State of California
The Resources Agency
Department of Water Resources
Division of Operations and Maintenance
Environmental Assessment Branch

Assessment of MTBE In State Water Project Reservoirs

Memorandum Report
April 1999

State of California **The Resources Agency**

M e m o r a n d u m

Date: April 20, 1999

To: Dan Peterson, Chief
Environmental Assessment Branch

Jeffrey Janik
Water Quality Control Specialist
From: **Department of Water Resources**

Subject: MTBE Study of Eight Reservoirs in the State Water Project During 1997– Memorandum Report

The Division of Operations and Maintenance conducted the attached study with assistance from field division staff at Delta, San Luis, Southern, Oroville, and Beckwourth Subcenter.

Objectives of the study were to assess the concentrations of methyl-tertiary butyl ether in eight reservoirs of the California State Water Project. Sampling was conducted in 1997 at Lake Davis, Lake Oroville and Thermalito Afterbay, Lake Del Valle, San Luis Reservoir and O'Neill Forebay, Pyramid Lake, Castaic Lake, Silverwood Lake, and Lake Perris. Sampling focused on the three summer holiday weekends of Memorial Day, July 4th, and Labor Day. The four specific objectives of the study were to: (1) define existing MTBE concentrations in SWP reservoirs; (2) define the vertical distribution of MTBE; (3) evaluate loading of MTBE during the summer recreational season; and (4) define the spatial heterogeneity of MTBE at boat launching ramps and reservoir index stations.

Results of the study showed that a large percentage of surface samples had MTBE levels that were elevated above the 1 μg/L (ppb) reporting level. MTBE was detected in 76 percent (54) of 71 samples. Highest concentrations were found in the southern reservoirs (lakes Perris, Castaic, Pyramid, and Silverwood) where MTBE was detected in 94 percent (31) of 33 surface samples at mean concentrations ranging from 6 to14 μg/L. MTBE concentrations declined with depth in the water column. No samples collected below the thermocline had MTBE concentrations greater than the DHS secondary MCL of 5 μg/L.

Samples collected from the 17 boat launching ramps also showed elevated levels with MTBE detected in 80 percent (104) of 130 samples. When MTBE was detected, 63 percent of the samples had concentrations greater than 5 µg/L and 27 percent (35) had MTBE levels greater than 10 µg/L. Highest MTBE concentrations were found near boat-launching at the four southern reservoirs where 19 percent of samples exceeded 20 µg/L with the mean ranging from 9 to 22 µg/L.

High boating activity during summer holiday weekends contributed to elevated MTBE concentration at all boat-launching ramps. In 43 percent (12) of 28 samples, MTBE increased by 2 µg/L or more after July 4th and Labor Day weekends.

If you have any questions or comments on this report, please call Jeffrey Janik, Environmental Assessment Branch, at (916) 653-5688.

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INTRODUCTION

Methyl tertiary-butyl ether (MTBE) is a colorless chemical oxygenate that oil refiners add to California's cleaner burning gasoline (11 percent by volume) to reduce air pollution and meet Federal Clean Air Standards. MTBE was first added to gasoline in 1979 to prevent engine knocking. Beginning in 1992, federal law required the use of oxygenated gasoline for winter driving in cities that exceeded the carbon monoxide air quality standard. Since 1996, gasoline containing MTBE was used year-round throughout California. A comprehensive report on health and environmental effects of MTBE was prepared by UC Davis and is available at:

http://www.tsrtp.ucdavis.edu/mtberpt/

MTBE was detected in groundwater monitoring wells in the early 1990's. The chemical typically enters groundwater from leaking underground storage tanks or pipelines. A June 1998 report by Lawrence Livermore National Laboratory concluded that MTBE has contaminated groundwater at over 10,000 shallow water monitoring sites in California. MTBE was detected in about 70 percent of the sites reported in that study. Wells in South Lake Tahoe, Santa Monica, Santa Clara, and Sacramento have been shut down due to MTBE contamination. A summary of sampling of public (groundwater) drinking water systems is available at the Department of Health Services (DHS) website:

http://www.dhs.ca.gov/ps/ddwem/chemicals/MTBE/mtbe_groundwater.htm

MTBE has also been found in surface waters in California used for drinking water. In Northern California, MTBE has been detected in a large number of lakes, including Lake Tahoe, Shasta Lake, Camanche Lake, Lake Pardee, and San Antonio Reservoir. The DHS website includes a list of reported detections of MTBE in surface water sources of drinking water:

http://www.dhs.ca.gov/ps/ddwem/chemicals/MTBE/mtbe_summary.htm#TABLE 4.

A major source of MTBE in surface waters is two-stroke gasoline engines. Two-stroke engines used on jet skis and many outboards discharge up to 25 percent of fuel/oil mixture into surface waters. Personal watercraft have been targeted by water and regulatory agencies because of the high MTBE loading into surface drinking waters. A number of restrictions are being proposed and implemented on the continued use of personal watercraft in drinking water reservoirs in the state. For example, Santa Clara Valley Water District recently approved new regulations that ban personal watercraft from Anderson Reservoir and reduce the number allowed on Calero and Coyote reservoirs.

MTBE Regulatory Issues (March 1999)

The following information can be found at the DHS website:

http://www.dhs.ca.gov/ps/ddwem/chemicals/MTBE/mtbe_standards.htm

DHS adopted a secondary maximum contaminant level (MCL) for MTBE of 5 ppb, effective January 7, 1999. The secondary MCL protects the public from exposure in drinking water at levels that can be smelled or tasted.

DHS is developing a primary MCL for MTBE which will be adopted later in 1999. The primary MCL includes consideration of health risks, the technical feasibility of meeting the MCL based on monitoring and water treatment requirements, and costs associated with compliance. DHS considers the public health goal (PHG) for the contaminant and generally sets the MCL at the level of the PHG. The PHG is a concentration of a contaminant in drinking water that does not pose any significant risk to health. Cal/EPA's Office of Environmental Health Hazard (OEHHA, 1999) adopted a 13 ppb PHG based on human health risks associated with MTBE in drinking water.

In 1991, DHS established a 35-ppb action level based on the non-carcinogenic effects of MTBE. In March 1999, DHS adopted a 13-ppb action level to protect against the adverse effect from a contaminant in drinking water when no health-based water quality standard exists. Once adopted, the primary MCL for MTBE will replace DHS' advisory "action level".

The California Air Resources Board (CARB) is developing a marine engine labelling program that will allow reservoir operators to regulate the type of marine engines allowed on reservoirs. CARB decided in December, 1998 to phase in regulations imposing exhaust limits on new outboard engines and personnel watercraft beginning in 2001.

The future of MTBE use in California was decided on March 25, 1999 when Governor Gray Davis ordered the chemical phased out of the states' gasoline supply by the end of 2002. California is seeking an immediate EPA waiver from the oxygenate mandates in the Clean Water Act. MTBE -free gasoline is being made available to some communities such as South Lake Tahoe that have been heavily impacted by MTBE leaking from underground storage tanks. Greater availability of MTBE-free gasoline may take longer; Chevron Corp. could remove all of the MTBE from its gasoline within 2 years.

Purpose and Scope

This report is an assessment of methyl-tertiary butyl ether (MTBE) in surface water reservoirs of the State Water Project in 1997. Sample collection focused on three summer holiday weekends; Memorial Day (May 24 - 26), Independence Day (July 4 - 6), and Labor Day (September 30 - August 1).

The specific objectives of this study were to (1) define existing MTBE concentrations in SWP reservoirs, (2) define the vertical distribution of MTBE, (3) evaluate the contribution of MTBE during the high use summer boating season, and (4) define spatial heterogeneity in MTBE levels at boat launching ramps and lake stations.

This is the first DWR report to investigate MTBE in State Water Project SWP. Water-quality in State Water Project reservoirs has been discussed previously (DWR 1991, 1995, 1997a).

Acknowledgments

DWR Water-quality staff were responsible for sample collection and coordinating the field activities. Thanks to Ralph Howell and Ron Vanscoy of Oroville Field Division, Beckwourth Subcenter; Ed Robbins, Thomas Odekirk, Kathie Lopez, and John Knox of Oroville Field Division; Richard Gage, George Anderson, and Doug Thompson of Delta Field Division; Tony McGraw, Pam Anaya, Mike Taliaferro, Ernie Severino, and Nikki Griffin of San Luis Field Division; and John Kemp, Gary Faulconer, Omar Conteh, and Della Stephenson of Southern Field Division.

Sample analysis was conducted at DWR's Bryte Chemical Laboratory. Thanks to Bill Nickels, Sid Fong, and Mark Bettencourt. DWR Graphic Services prepared maps of the sampling sites.

DESCRIPTION OF STUDY AREA

The eight main reservoirs of the State Water Project (SWP) have a combined storage capacity of more than 6 million acre-feet (MAF) (**Table 1**). *Lake Davis*, located in Plumas County, was the most northern waterbody included in this study **(Fig 1)**. *Lake Oroville* in Butte County stores Feather River runoff to a maximum of 3.5 MAF. Water flows down natural channels to the Sacramento-San Joaquin Delta where it is pumped by the Harvey O. Banks Delta Pumping Plant into the 444-mile long California Aqueduct and 42-mile long South Bay Aqueduct. *Lake Del Valle* is a storage reservoir located on the South Bay Aqueduct.

Table 2. Types of boating in SWP reservoirs.

Reservoir	Motorized craft 2/4 stroke	Motorized craft PWC	Water-skiing
Lake Davis	•	*	No
Lake Oroville	•	•	•
Thermalito Afterbay	•	•	•
Lake Del Valle	• *	No	No
San Luis Reservoir	•	•	•
O'Neill Forebay	•	•	•
Silverwood Lake	•	•	•
Lake Perris	•	•	•
Pyramid Lake	•	•	•
Castaic Lake - East Arm	•	No	No
- West Arm	•	•	•

* 10 mph maximum speed
PWC = Personal watercraft (jetskis)
* Not prohibited (see text for discussion)

Water in the main California Aqueduct travels along the west side of the San Joaquin Valley, 63 miles to *O'Neill Forebay* and *San Luis Reservoir* with a maximum of 2.04 MAF. SWP water flows south to the Tehachapi Mountains, where the A.D. Edmonston Pumping Plant raises the water 1,926 feet to 10 miles of tunnels and siphons which traverse the Tehachapi mountain range. After crossing the Tehachapis, the Aqueduct divides into two branches. The West Branch Aqueduct conveys water to *Pyramid Lake* and *Castaic Lake* to serve Los Angeles and other coastal cities. The East Branch Aqueduct flows through the Antelope Valley, storing water in *Silverwood Lake* and *Lake Perris* in Riverside County.

There are few restrictions on boating activity in SWP reservoirs (**Table 2**). Water skiing is not allowed on Lake Davis, Lake Del Valle, and the east arm of Castaic Lake. In addition, personal watercraft are not allowed on the east arm of Castaic Lake and Lake Del Valle which also has a maximum speed limit of 10 m.p.h. The east arm of Castaic Lake is designated for slow boating (fishing and sailing). The main limitation to boating in SWP reservoirs is the availability of parking spaces for boats and trailers. Parking lots at southern California reservoirs are full during every weekend of the summer recreational season.

Table 1. Physical characteristics of SWP reservoirs.

Reservoir	Physical characteristics: Max. Vol (acre-feet)	Surface area (ac)	Max. depth ft	Max. depth m	Mean depth ft	Mean depth m
Lake Davis	84,370	4,030	108	33	21	6
Lake Oroville	3,537,580	15,810	690	210	224	68
Thermalito Afterbay	57,040	4,300			13	4
Lake Del Valle ‡	40,000	708	139	42	56	17
San Luis Reservoir	2,027,840	12,520	274	84	162	49
O'Neill Forebay	56,430	2,700	40	12	21	6
Silverwood Lake	74,970	980	166	51	77	23
Lake Perris	131,450	2,320	110	34	57	17
Pyramid Lake	171,200	1,300	355	108	132	40
Castaic Lake	323,700	2,240	330	101	145	44

‡ Recreational elevations

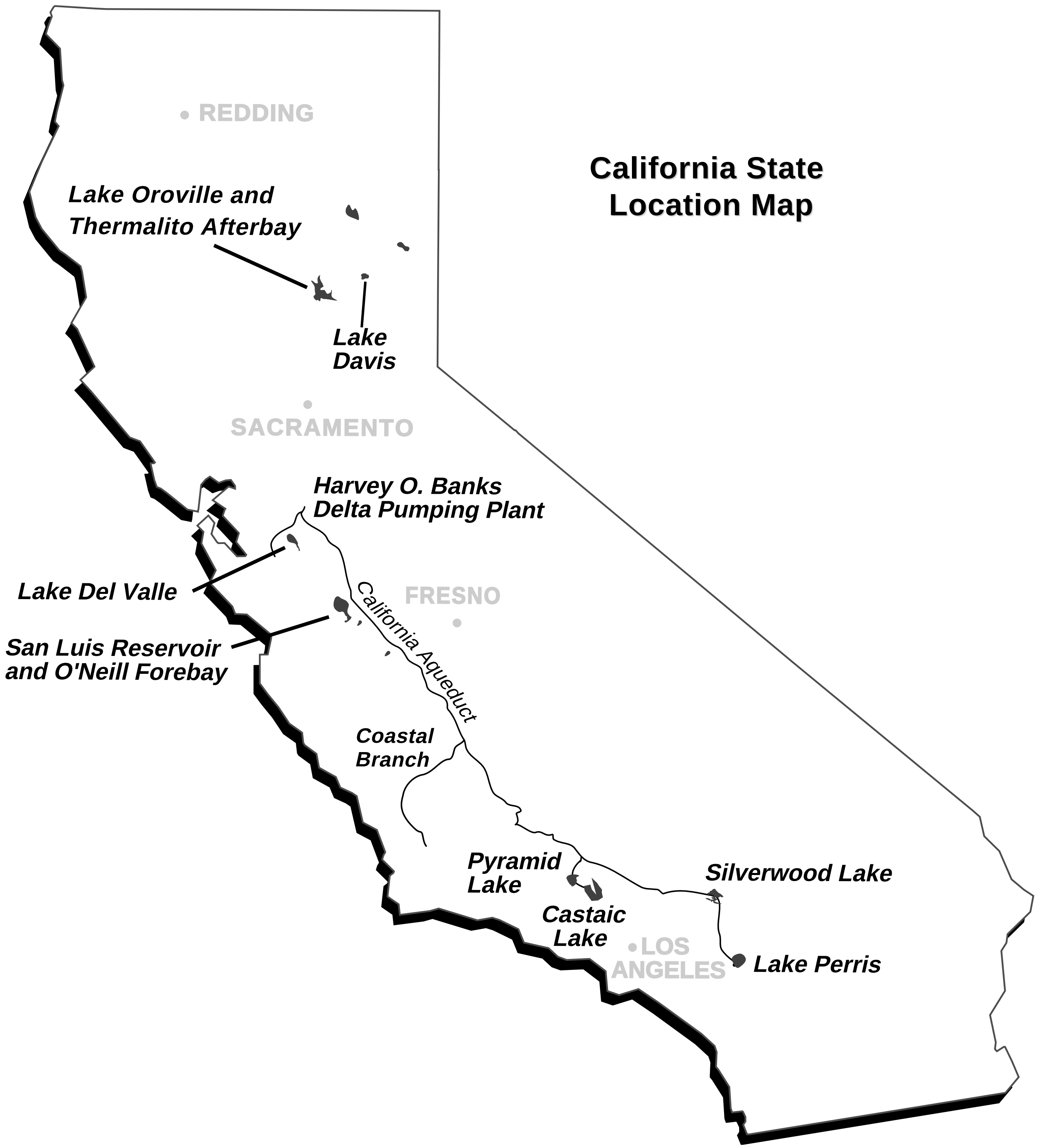

Figure 1. Map of State Water Project reservoirs sampled for MTBE in 1997.

METHODS

MTBE Sample Collection

Sampling was conducted at 8 SWP reservoirs, 1 forebay and 1 afterbay (**Table 3**). Reservoir samples were collected at an index station located near the outlet or dam. In addition, 17 sites were sampled near boat launching ramps. Sampling depths and dates are discussed in the individual reservoir sections.

MTBE samples were collected with either a Van Dorn or Kemmerer water sampler rinsed with distilled-deionized water before each sample. Prior to sampling, the boat motor was shut down to reduce MTBE contamination and samples were collected from the boat bow. Three 40 mL Borosilicate screw cap vials with teflon-silicon septa were filled at each site. Each vial contained 2 drops of 1:1 HCl and was filled until a convex meniscus was formed. Samples were checked for bubbles by inverting the capped vial and tapping it lightly. Vials with air bubbles were discarded and a new vial was filled.

Field Quality Assurance

Field Reagent Blanks (Travel Blanks) - duplicate 40 mL vials were filled in the laboratory with reagent water, sealed, and shipped to the sampling site with the empty sample vials. After sample collection, the travel blanks were shipped back to the laboratory with filled sample vials. Travel blanks identify contamination during transportation to the laboratory. MTBE was not detected in any of the field reagent blanks.

Field Blanks - collected by filling two 40 mL vials with organic free water at each reservoir. Volatile organic free water was prepared by bubbling high grade helium gas through distilled-deionized water for 4 to 8 hours. The purged water was then analyzed for volatiles. Only one field blank, collected at San Luis Reservoir on 6-Aug-97, had a detectable concentration (1.4 μg/L) of MTBE.

Equipment blanks - collected at each reservoir at the completion of a sampling day. The water sampler was first rinsed with distilled-deionized water and the rinse discarded. A second rinse with about 200 mL of organic free water was used to fill two 40-mL vials. These samples were used to define contamination during field sampling. No equipment blanks during this study had detectable levels of MTBE.

Samples (field and all blanks) were isolated from potential sources of contamination by placing them in individual plastic bags. The bags were stored in an ice chest at 4° C and shipped to the laboratory within 24 hours. Travel, field and equipment blanks were analyzed following the same methods as field samples.

Sample Analysis

MTBE analysis was performed using EPA Method 502.2 at DWR's Bryte Chemical Laboratory in West Sacramento, CA. The Purge and Trap System consisted of a Tekmar LSC 2000 modified with moisture control module, and interfaced with a Tekmar ALS 2016 automatic sampler. Gas chromatography system was a Hewlett Packard 5890 Series II chromatograph equipped with 4430 photoionization detector and 4420 conductivity detector. Each sample with detectable levels of MTBE was confirmed by either spiking the sample and re-analyzing or by confirmation using GC/MS. A detectable concentration of MTBE was greater or equal to the minimum reporting level of 1 microgram per liter (μg/L) or part per billion (ppb).

Quality Assurance in the laboratory followed standard procedures for Method 502.2 including ongoing analysis of laboratory performance check solutions, laboratory reagent blanks, laboratory fortified blanks, and laboratory control samples to evaluate and document data quality.

Table 3. MTBE sampling sites in the State Water Project, 1997.

[• Indicates boat launching ramp or marina.]

Station number	Station name	No. depths sampled
LD001	Lake Davis at Grizzly Valley Dam	3
• LD-HC	Lake Davis at Honker Cove	1
OR001	Lake Oroville at Oroville Dam	3
• OR-BC	Lake Oroville at Bidwell Canyon	1
• OR-LC	Lake Oroville at Loafer Creek	1
• OR-LS	Lake Oroville at Lime Saddle	1
• TA-MH	Thermalito Afterbay at Monument Hill	1
• DV003	Lake Del Valle at Eastside Boat Launch	1
DV0025	Lake Del Valle - 1.4 mi. NW of DV003	1
DV0020	Lake Del Valle at mid-lake - 2.3 mi. NW of DV003	1
DV001	Lake Del Valle near dam - 3.9 mi. NW of DV003	3
SL001	San Luis Reservoir at trashracks	3
SL005	San Luis Reservoir at Pacheco Intake	1
• SL-DP	San Luis Reservoir at Dinosaur Point	1
• SP-BA	San Luis Reservoir at Basalt Area	1
ON005	O'Neill Forebay at O'Neill Pumping Plant outlet	3
• ON-SLC	O'Neill Forebay at San Luis Creek	1
• ON-MA	O'Neill Forebay at Medeiros Area	1
PY001	Pyramid Lake at Tunnel Inlet	3
• PY-VA	Pyramid Lake at Vaquero	1
• PY-SE	Pyramid Lake at Serrano	1
• PY-EL	Pyramid Lake at Emigrant Landing	1
CA002	Castaic Lake at Outlet tower	3
• CA-ER	Castaic Lake at East boat ramp	1
• CA-WR	Castaic Lake at West boat ramp	1
SI002	Silverwood Lake at San Bernardino Tunnel	3
• SL-SC	Silverwood Lake at Sawpit Canyon	1
PE002	Lake Perris at outlet	3
• PE-BR	Lake Perris at boat ramp	1

Summary

Surface MTBE at Boat Launching Ramps

A total of 130 samples were analyzed for MTBE from 17 boat launching ramps in SWP reservoirs (**Table 4**). MTBE was detected (>1 µg/L) in 80 percent (104) of 130 surface samples. MTBE was detected in every sample from boat launching ramps with the exception of San Luis Reservoir, O'Neill Forebay and Thermalito Afterbay. When MTBE was detected, 63 percent of samples had concentrations greater than 5 µg/L. Twenty-seven percent (35) of 104 ramp samples had MTBE levels greater than 10 µg/L.

Excluding the San Luis Reservoir Complex (San Luis Reservoir and O'Neill Forebay), MTBE was detected in 97 percent (103) of 107 boat ramp samples. MTBE was detected in 100 percent of the boat ramp samples from Lake Davis, Lake Oroville, Lake Del Valle, Pyramid Lake, Castaic Lake, Silverwood Lake, and Lake Perris.

MTBE was highest in the 4 southern California reservoirs where 82 percent (46) of 56 samples had MTBE concentrations greater than 5 µg/L. MTBE was greater than 10 µg/L in almost 60 percent (33) of 56 samples. In 3 of the 4 southern reservoirs (Pyramid, Castaic, and Perris), 19 percent (9) of 47 boat ramp samples had MTBE concentrations greater than 20 µg/L.

These data show that MTBE was detected at a high frequency in samples from SWP boat launching ramps and at concentrations much higher than the reporting level of 1 µg/L.

Table 4. MTBE at boat ramps in State Water Project reservoirs.
[Number in parenthesis indicates number of boat ramps sampled at each reservoir; nd, not-detected; n. number of samples]

Reservoir	Number of Samples	MTBE (µg/L) nd		1 - 5		6 -10		11 - 20		≥ 20	
		%	n	%	n	%	n	%	n	%	n
Lake Davis (1)	5	0	0	80	4	0	0	20	1	0	0
Lake Oroville (3)	24	0	0	67	16	33	8	0	0	0	0
Thermalito Afterbay (1)	8	38	3	50	4	0	0	13	1	0	0
Lake Del Valle (1)	13	0	0	31	4	69	9	0	0	0	0
San Luis Reservoir and O'Neill Forebay (4)	24	96	23	4	1	0	0	0	0	0	0
Pyramid Lake (3)	24	0	0	29	7	29	7	33	8	8	2
Castaic Lake (2)	15	0	0	7	1	20	3	53	8	20	3
Silverwood Lake (1)	9	0	0	22	2	33	3	44	4	0	0
Lake Perris (1)	8	0	0	0	0	0	0	50	4	50	4
Total S. Reservoirs	*56*		*0*		*10*		*13*		*24*		*9*
All Res. - Total	**130**		**26**		**39**		**30**		**26**		**9**

Surface MTBE at Reservoir Stations

MTBE was detected in 76 percent (54) of 71 surface samples from SWP reservoirs. All surface samples from Castaic, Silverwood, and Lake Perris had detectable levels of MTBE (**Table 5**).

Highest MTBE was found in the four southern reservoirs (lakes Pyramid, Castaic, Silverwood, and Perris) where MTBE was detected in 94 percent (31) of 33 samples. At those reservoirs, MTBE was greater than 5 µg/L in 76 percent (26) of 33 samples. Mean surface MTBE at each of those four reservoirs was also greater than 5 µg/L **(Fig. 2)**. At Pyramid and Silverwood, mean surface MTBE was 6 µg/L and 7 µg/L, respectively. Mean surface MTBE was about twice as high at Castaic (12 µg/L) and Perris (14 µg/L) for the sampling period.

MTBE was lower in northern and central SWP reservoirs. Thirty nine (39) percent of those samples (15 of 38) were below detection compared to 6 percent (2 of 33 samples) in southern SWP reservoirs. In San Luis Reservoir and O'Neill Forebay, MTBE was detected in only 3 of 12 surface samples and not detected in subsurface samples. No surface samples from Lake Davis, Del Valle (DV001), Oroville, or San Luis had MTBE greater than 5 µg/L. Mean surface MTBE was at the reporting level of 1 µg/L at Lake Oroville and Lake Davis **(Fig 2)**. Lake Oroville has a large water volumes and boating activity at Oroville and Davis is low compared to the southern SWP reservoirs.

At Lake Del Valle (station DV001), mean surface MTBE was 3 µg/L. Epilimnetic MTBE at Lake Del Valle calculated based on the areal weighting of the four stations (DV001, DV002, DV0025, and Eastside Boat ramp, DV003) was 3.5 µg/L **(Fig 2)**. Personal watercraft (PWC) are not permitted at Lake Del Valle and the maximum speed is 10 m.p.h.

Table 5. Surface MTBE by concentration intervals in State Water Project Reservoirs, 1997.
[nd, not-detected; n. number of samples]

Reservoir	Number of Samples	MTBE (µg/L) nd %	nd n	1 - 5 %	1 - 5 n	6 -10 %	6 -10 n	11 - 20 %	11 - 20 n	≥ 20 %	≥ 20 n
Lake Davis	5	60	3	40	2	0	0	0	0	0	0
Lake Oroville	8	25	2	75	6	0	0	0	0	0	0
Lake Del Valle (DV001)	13	8	1	92	12	0	0	0	0	0	0
San Luis Reservoir	6	100	6	0	0	0	0	0	0	0	0
O'Neill Forebay	6	50	3	50	3	0	0	0	0	0	0
Total	**38**	**39**	**15**	**61**	**23**	**0**	**0**	**0**	**0**	**0**	**0**
Pyramid Lake	8	25	2	0	0	50	4	25	2	0	0
Castaic Lake	8	0	0	13	1	38	3	38	3	13	1
Silverwood Lake	9	0	0	44	4	56	5	0	0	0	0
Lake Perris	8	0	0	0	0	25	2	63	5	13	1
Total S. Reservoirs	**33**	**6**	**2**	**15**	**5**	**42**	**14**	**30**	**10**	**6**	**2**
All Res. - Total	**71**		**17**		**28**		**14**		**10**		**2**

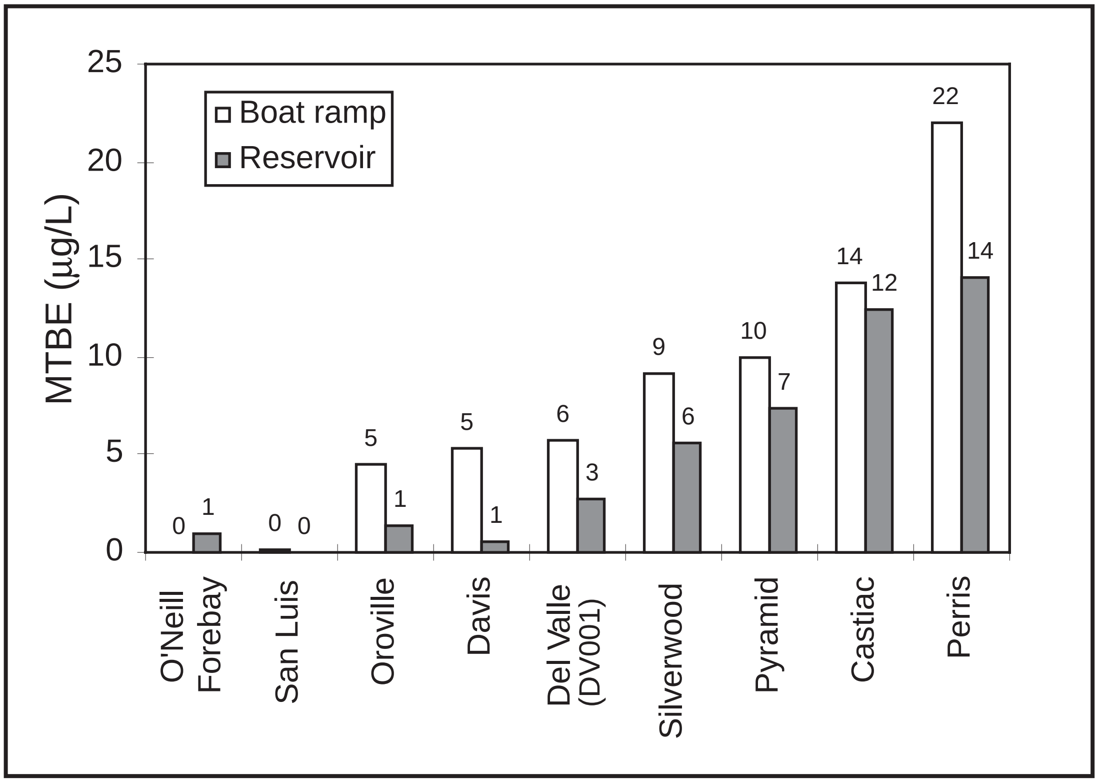

Figure 2. Mean surface MTBE as µg/L at boat launching ramps and reservoir stations in the State Water Project, 1997.

Mean surface MTBE was greater than 5 µg/L at Silverwood, Pyramid, Castaic, and Lake Perris (**Fig. 2**). When MTBE was detected, mean surface values were higher near boat launching ramps than reservoir stations. Mean surface MTBE within a reservoir was 2 µg/L to 8 µg/L higher at boat ramps compared to the index station.

The greatest difference was found at Lake Perris where MTBE at the boat ramp was 22 µg/L compared of 14 µg/L at the reservoir Outlet. Lake Perris had the highest mean boat ramp and reservoir MTBE concentration of 22 µg/L and 14 µg/L, respectively.

Table 6. Change in surface MTBE (μg/L) after July 4th and Labor Day weekends at SWP reservoirs, 1997.
[Number in parenthesis indicates number of boat ramps used to compute mean at each reservoir]

	July 4th				Labor Day			
	Pre	Post	Change	%	Pre	Post	Change	%
BOAT RAMPS								
Lake Davis (1)	0.0	2.0	2.0	-	4.0	15.0	11.0	73
Lake Oroville (3)	4.1	6.4	2.3	36	4.6	7.4	2.8	38
Lake Del Valle (1)	5.5	8.5	3.0	35	4.4	6.0	1.6	27
Pyramid Lake (3)	9.2	10.7	1.5	14	13.9	16.7	2.8	17
Castaic Lake (2)	13.0	16.5	3.5	21	16.5	18.0	1.5	8
Silverwood Lake (1)	12.0	13.0	1.0	8	8.8	10.0	1.2	12
Lake Perris (1)	21.0	28.0	7.0	25	30.0	32.0	2.0	6
RESERVOIR								
Lake Davis	0.0	2.1	2.1	-	0.0	0.0	-	-
Lake Oroville	1.8	3.0	1.2	40	1.2	2.0	0.8	40
*Lake Del Valle	3.5	3.8	0.3	8	2.3	2.6	0.3	12
Pyramid Lake	7.8	11.0	3.2	29	9.9	9.2	-0.7	-8
Castaic Lake	8.8	24.0	15.2	63	15.0	15.0	0.0	0
Silverwood Lake	6.0	7.2	1.2	17	3.5	5.7	2.2	39
Lake Perris	17.0	21.0	4.0	19	17.0	16.0	-1.0	-6

* Del Valle - DV001

MTBE was measured before and after Independence Day and Labor Day. Some samples were collected during Memorial Day weekend but the dataset was not complete for all SWP reservoirs. San Luis Reservoir Complex was not included in this table because most of the samples were below detection.

MTBE increased over Independence Day and Labor Day at all boat ramp stations. Post holiday MTBE was higher than pre-holiday values by 1.0 μg/L or more in 71 percent (20) of 28 samples. In 43 percent (12) of 28 samples, MTBE was more than 2.0 μg/L higher after the holiday weekends. Mean MTBE at all boat ramps increased by 2.9 μg/L and 3.3 μg/L following July 4th and Labor Day holidays, respectively.

At reservoir stations, MTBE increased at all 7 sites following July 4th weekend. Post-holiday MTBE was higher by 1.2 to 4.0 μg/L in 71 percent (5) of 7 samples. The change in MTBE levels were less after the Labor Day weekend than July 4th. MTBE decreased or changed by less than 1 μg/L in 86 percent (6) of 7 samples. Mean MTBE for all reservoir stations increased by 3.9 μg/L and 0.3 μg/L following July 4th and Labor Day, respectively.

Lake Davis

Lake Davis is located in northern California about 8 miles north of Portola in the Plumas National Forest. The lake was formed in 1967 with the construction of Grizzly Valley Dam. This reservoir is the most northern of those examined and has a maximum storage capacity of 84, 370 acre-ft. and surface area of 4,026 acres (**Table 1**).

Recreation, fish and wildlife enhancement, and domestic water supply are the main purposes of the lake. Water skiing is not allowed although personal watercraft are permitted. Personal watercraft use is low because of cold water temperature during the summer and the abundance of aquatic weeds along the shore. Personal watercraft use is higher at nearby Frenchman Lake. Lake Davis has one privately owned boat livery at Coot Bay near the dam with about 10 to 12 rental boats.

Drinking water for the nearby town of Portola is obtained from the lake which is equipped with outlet valves at 5,740 feet (1749.6 m) and 5,760 feet elevation (1755.7 m) permitting withdrawal at selected depths for control of temperature and water quality. During this survey, the surface elevation decreased by 2 feet from 5769 feet (1758.4 m) in July to 5767 feet (1757.8 m) on September 2, 1997.

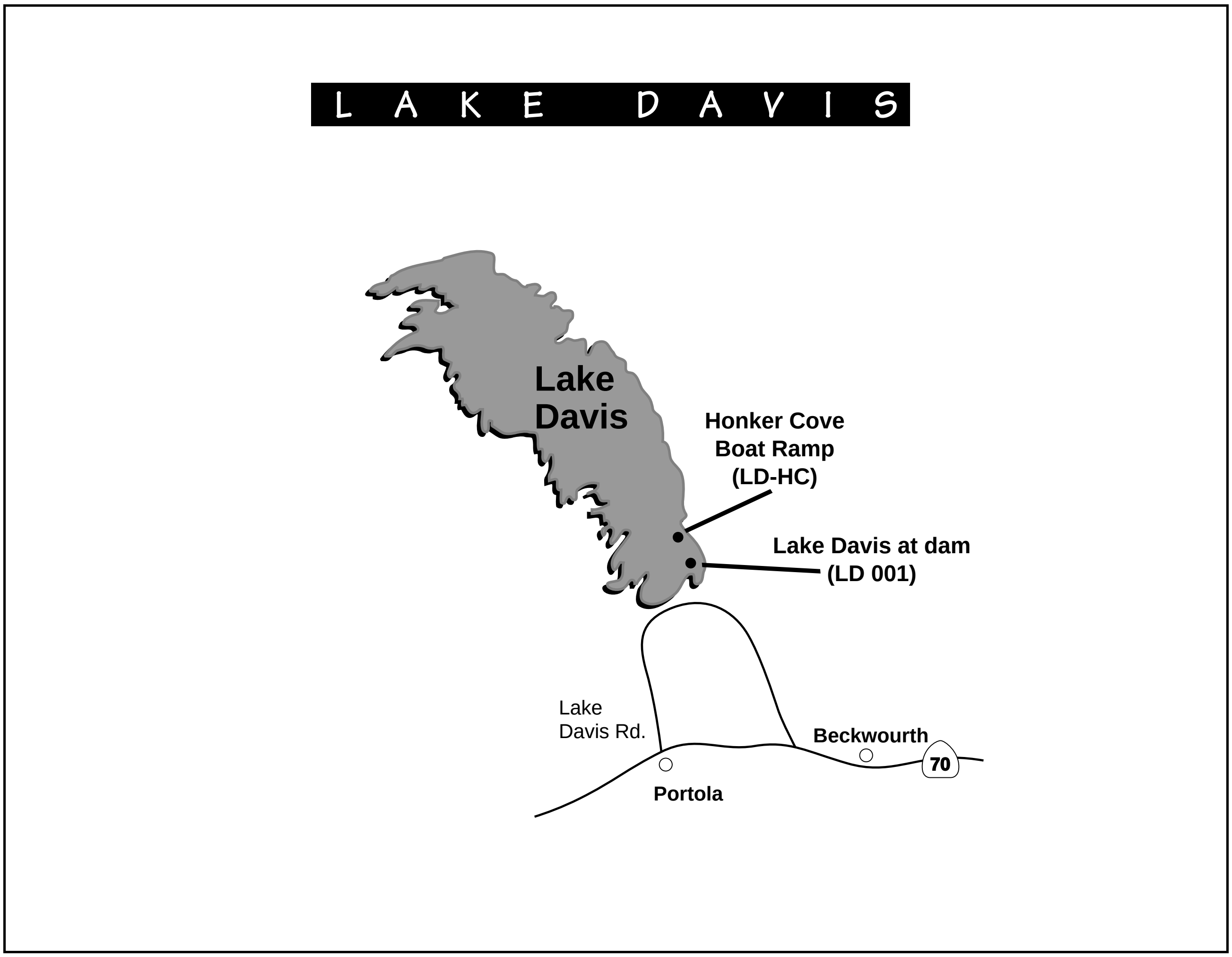

Figure 3. Map of Lake Davis sampling sites, 1997.

Two sites were sampled from May to September 1997. Samples were collected from the surface (0.5 m), and at depths corresponding to the upper and lower outlet valves at Grizzly Valley Dam (LD001). Depending on reservoir surface elevation, the outlet valves were at depths of about 2.5 m (upper) and 8.5 m (lower). Surface samples were taken at Honker Cove boat ramp (LD-HC), located on the east side of the reservoir, north of Grizzly Valley Dam (**Fig. 3**).

Sampling ended after Labor Day weekend due to lake drawdown and closure to recreational boating. The lake was treated with 16,000 gallons of Nusyn-Noxfish, and 32 tons of powdered rotenone on October 15th by the California Department of Fish and Game to eradicate northern pike. The lake remained closed to fishing until July of 1998. As of April 1999, the lake was still not used as a source of drinking water although approved by the Department of Health Services for human consumption.

Results - Lake Davis

At Grizzly Valley Dam, MTBE was detected in 40 percent (2) of 5 surface samples, at values of 1 and 2 μg/L (**Table 7).** MTBE at the 2.5 m depth was detected in 1 sample and not detected at the 8.5 m depth.

MTBE was detected in all 5 surface samples collected at Honker Cove Boat ramp at concentrations of 1 to 15 μg/L. The highest value of 15 μg/L was found on 2-Sept- 97, the day after Labor Day weekend.

There was no clear trend in the data from sampling before and after the holidays. Post holiday MTBE was higher is 3 cases, lower in one, and with 4 cases below detection both before and after the holidays. At Grizzly Valley Dam, MTBE increased from below detection to 2 ug/L over the July 4th weekend. The change in MTBE was greatest at Honker Cove Boat ramp where MTBE increased by 11 μg/L over Labor Day but decreased by 1 μg/L during the Independence Day weekend (**Table 7**).

Table 7. Monthly MTBE in Lake Davis at Grizzly Valley dam and Honker Cove Boat ramp, 1997.
[nd, non-detectable = <1 μg/L]

Station	Depth (m)	27-May	MTBE (μg/L) 3-Jul	7-Jul	29-Aug	2-Sep
Grizzly Valley Dam	0.5	1	nd	2	nd	nd
	2.5	nd	nd	1	nd	nd
	8.5	nd	nd	nd	nd	nd
Honker Cove Boat Ramp	0.5	1	4	3	4	15

Table 8. Volatile organic compounds detected in Lake Davis, 1997. MTBE (µg/L) also shown.

Date	Station	Depth (m)	VOC	µg/L
3-Jul-97	Honker Cove	0.5	MTBE	3.6
			Toluene	0.7
29-Aug-97	Honker Cove	0.5	MTBE	3.7
			Toluene	1.4
2-Sep-97	Honker Cove	0.5	MTBE	15.0
			Toluene	1.5

In addition to MTBE, toluene was detected in 60 percent (3) of 5 samples from Honker Cove Boat ramp. When detected, toluene ranged in concentration from 0.7 to 1.5 µg/L (**Table 8**). No VOC's other than MTBE were detected at Grizzly Valley Dam

In summary, Lake Davis MTBE concentrations were low throughout the summer of 1997. MTBE at the Honker Cove Boat ramp was detected in all 5 samples with a mean of 5.3 µg/L (**Table 9**). Concentrations at the reservoir outlet were either at or below the reporting level of 1 µg/L. It appears that the overall low level of boating which included an absence of water skiing and minimal amount of personal watercraft use contributed to the low MTBE concentrations in Lake Davis.

Table 9. Mean MTBE (µg/L) in Lake Davis, 1997.
[S, surface (0.5 m); n, number of samples; S.D., standard deviation; nd, non-detectable]

	Depth	Mean	n	S.D.
Boat ramp				
Honker Cove	S	5.3	5	5.5
Reservoir				
Dam (LD001)	z1	0.6	5	0.9
	z2	0.3	5	0.6
	z3	nd	5	-

Lake Oroville and Thermalito Afterbay

Lake Oroville is the largest reservoir in the SWP with a storage capacity of 3,537,580 ac-ft. The volume is second to Lake Shasta in California. Winter and spring runoff is stored and released into the Feather River. Recreational activities include sail and power boating, water skiing, fishing, swimming, and boat-in camping.

Monthly samples were collected from late May to November, 1997 at three boat launching areas and Oroville Dam. Surface samples were taken at Bidwell Canyon, Lime Saddle, and Loafer Creek boat ramps (**Fig. 4**). Bidwell Canyon and Loafer Creek are located near the dam in the southern end of the reservoir. Lime Saddle is in the northwest arm. Fuel docks are operated at Bidwell Canyon and Lime Saddle.

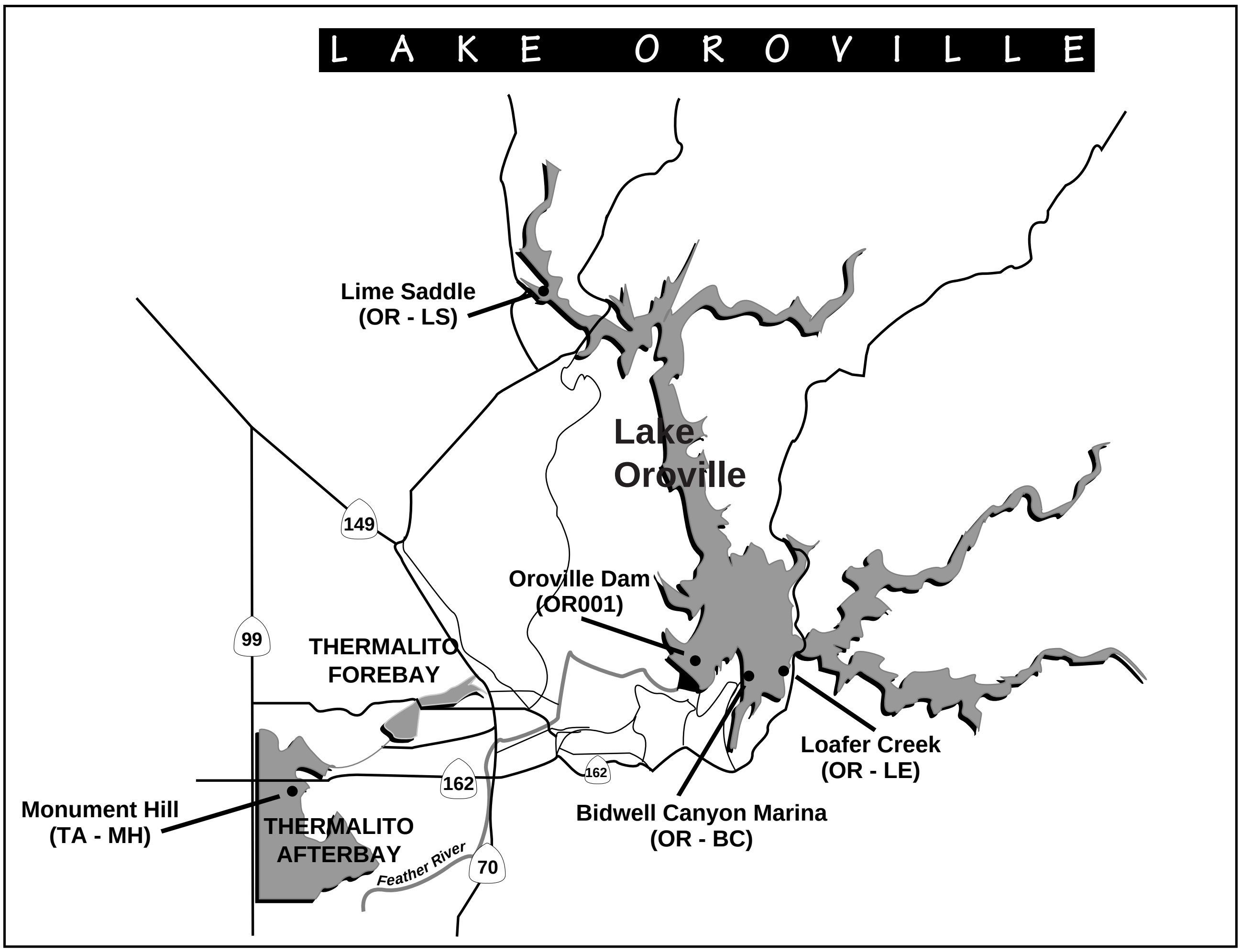

Figure 4. Map of Lake Oroville and Thermalito Afterbay sampling sites, 1997

Table 10. Sample and thermocline depths (m) and surface elevation in Lake Oroville, 1997.

Date	Sample depth (m) z1	z2	z3	Thermo-cline	Surface elev. (m)
5/27/97	0.5	6.1	36.6	8.0	267.9
7/03/97	0.5	9.8	30.5	12.0	261.3
7/07/97	0.5	7.9	24.4	12.0	260.1
8/06/97	0.5	7.3	20.4	12.0	248.1
8/29/97	0.5	8.5	24.4	14.0	243.7
9/02/97	0.5	8.5	24.4	14.5	243.9
10/02/97	0.5	9.6	33.5	22.0	242.0
11/06/97	0.5	13.4	36.6	33.0	239.3

Table 11. Mean MTBE (µg/L) in Lake Oroville, 1997.

[S, surface (0.5 m); n, number of samples; S.D., standard deviation; nd, non-detectable=<1.0 µg/L]

	Depth	Mean	n	S.D.
Boat ramps				
Lime Saddle	S	5.6	8	2.6
Loafer Creek	S	5.5	8	2.0
Bidwell Canyon	S	2.3	8	0.9
Mean		4.5	24	2.4
Reservoir				
Dam (OR001)	z1	1.4	8	1.0
	z2	1.3	8	1.7
	z3	nd	8	-

Three depths were sampled at Oroville Dam; surface (0.5 m), lower epilimnion above the thermocline at 6 to 13 m, and the hypolimnion (20 - 37 m). Depth of the thermocline ranged from about 8 m in May to 33 m in November before the lake mixed (**Table 10).**

Results - Lake Oroville

MTBE was detected in all surface samples collected at the three boat ramps (**Fig. 5**). Concentrations ranged from 2 to 9 µg/L (mean = 5.6) at Lime Saddle, 3 to 9 µg/L (mean = 5.5) at Loafer Creek, and 1 to 4 µg/L at Bidwell Canyon with a mean of 2.3 µg/L (**Table 11**). Seasonally, MTBE increased during the summer with the highest concentrations occurring from July 7 to September 2, corresponding to the peak boating period.

MTBE ranged from 6 to 9 µg/L at Lime Saddle and Loafer Creek from Independence Day to Labor Day weekends. MTBE at Bidwell Canyon was lower, in the range of 2 to 4 µg/L during the same July to September period.

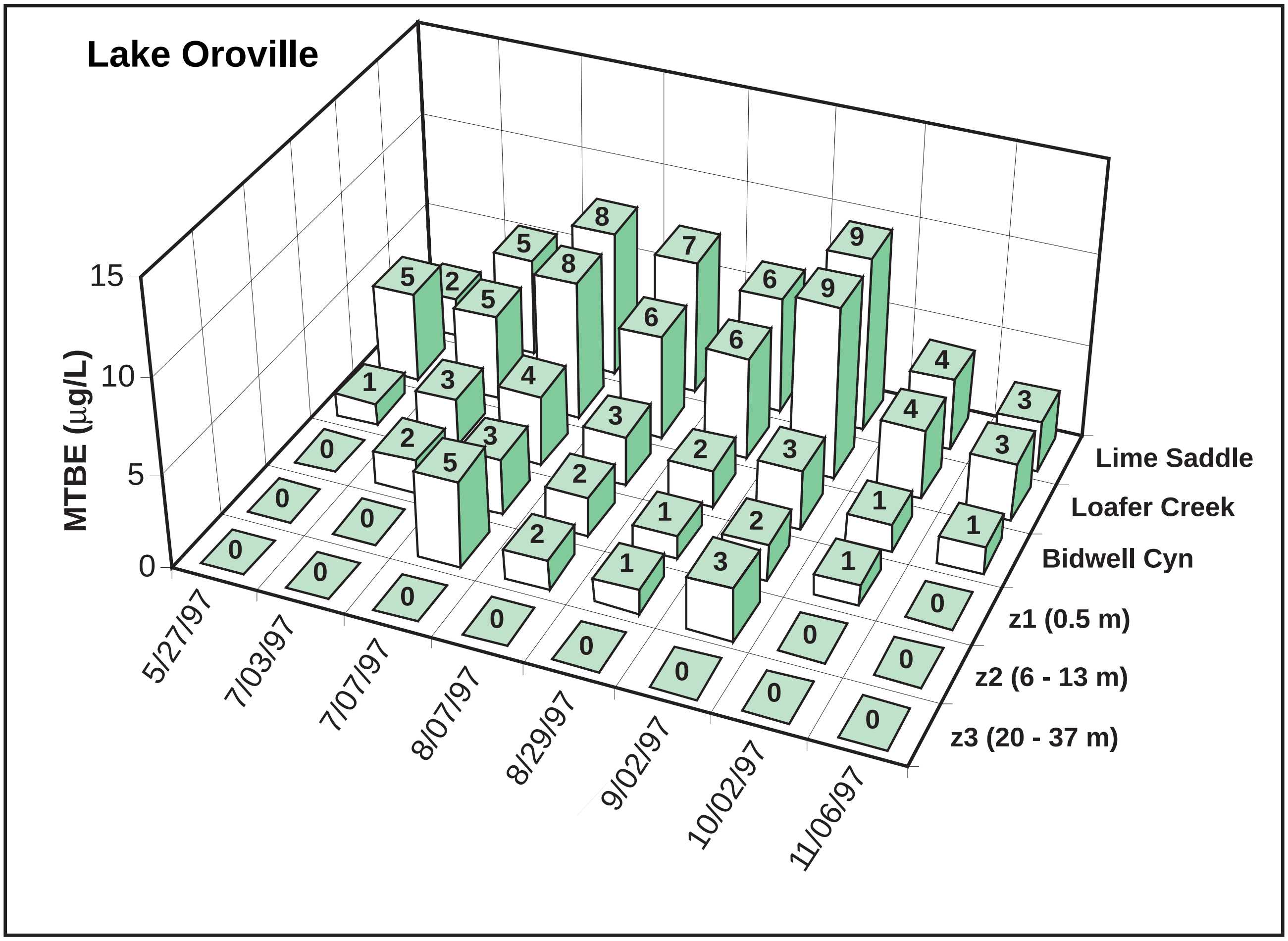

Figure 5. Monthly MTBE concentrations in Lake Oroville, 1997.

At Oroville Dam, MTBE was detected in 75 percent (6) of 8 surface samples. Concentrations were similar to Bidwell Canyon and ranged from below detection to 3 µg/L. MTBE was detected in 50 percent (4) of 8 samples from mid-depth (z2) of 6 to 13 m (**Table 10**). During the peak recreational period MTBE ranged from 2 to 5 µg/L. On July 7, MTBE was higher at 8 m depth (z2) than the surface. MTBE was not detected in the hypolimnion at 20 to 37 m.

Relationship of MTBE and thermal stratification - Lake Oroville was thermally stratified with a thermocline at 8 m during the first sampling on 27-May-97. Depths z1 and z2 were collected within the freely circulating epilimnion while z3 was within the hypolimnion. The thermocline was located at 12 m during July and early August. Samples from z1 and z2 were located within the epilimnion throughout the remainder of the monitoring period. Thermal stratification weakened in early October with the thermocline positioned at 22 m. The lake mixed in November.

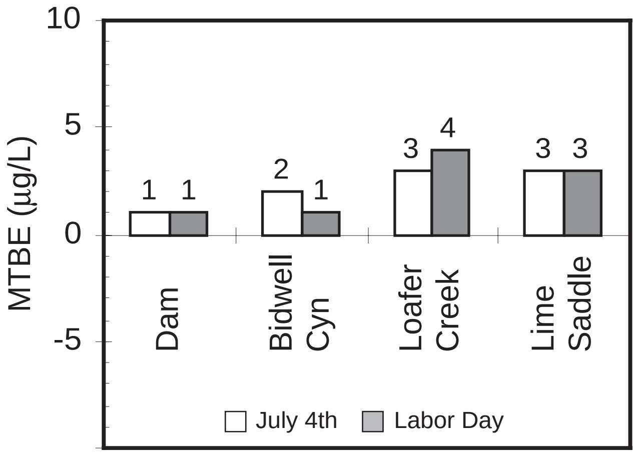

Figure 6. Change over holiday weekends in surface MTBE (µg/L) at Lake Oroville; July 4th = MTBE on 7-Jul-97 — 3-Jul-97; Labor Day = 2-Sep-97 — 29-Aug-97. Positive numbers indicate an increase.

Post-holiday MTBE concentrations were higher than pre-holiday values at the three boat ramps and Oroville Dam (**Fig. 6**). The greatest post-holiday increase was found at Loafer Creek and Lime Saddle boat ramps where MTBE increased by 3 to 4 µg/L. MTBE increased by 1 to 2 µg/L at Bidwell Canyon and Oroville Dam during the two holiday weekends.

Loafer Creek boat ramp was the only site sampled in Lake Oroville where BTEX compounds were detected (**Table 12**). Both toluene and MTBE were detected in 63 percent (5) of 8 samples at concentrations ranging from 0.7 to 2.4 µg/L. In addition, both xylene and MTBE were detected in 50 percent (4) of 8 samples. Three VOC's (MTBE, toluene and xylene) were detected in 50 percent (4) of 8 samples. The reason for detectable levels of BTEX compounds and MTBE at Loafer Creek is not clear especially since monthly MTBE concentrations were similar to Lime Saddle. In addition, Loafer Creek is the only boat launching site of the three without a fuel dock.

In summary, elevated levels of MTBE were found in all surface samples collected at the three boat ramps: Lime Saddle, Loafer Creek, and Bidwell Canyon. At Oroville Dam, MTBE was detected in all surface samples except at the beginning (May) and end of the boating season (November). MTBE was found in 50 percent (4) of 8 samples collected from the lower epilimnion (z2) at depths of 6 to 13 m at Oroville dam. MTBE was higher following Independence Day and Labor Day weekends. At Lime Saddle and Loafer Creek, MTBE increased nearly 1 µg/L per day during those holidays.

Table 12. MTBE and BTEX compounds detected in Lake Oroville, 1997.

Date	Station	Depth (m)	VOC's	µg/L
7-Jul-97	Loafer Creek boat ramp	0.5	MTBE	8.0
			Toluene	2.0
			Total xylene	1.9
7-Aug-97	Loafer Creek boat ramp	0.5	MTBE	6.0
			Toluene	0.7
29-Aug-97	Loafer Creek boat ramp	0.5	MTBE	6.0
			Toluene	1.4
			Total xylene	1.7
3-Sep-97	Loafer Creek boat ramp	0.5	MTBE	9.0
			Toluene	2.4
			Total xylene	3.2
2-Oct-97	Loafer Creek boat ramp	0.5	MTBE	4.0
			Toluene	0.9
			Total xylene	0.7

Thermalito Afterbay

Thermalito Afterbay is 4.5 miles downstream from Oroville Dam with a storage volume of 57,040 acre-feet. Thermalito Diversion Dam diverts water into Thermalito Power Canal for power generation at Thermalito Powerplant and creates a tailwater pool for Thermalito Powerplant. The impounded water acts as a forebay when Edward Hyatt Powerplant is pumping water back into Lake Oroville (DWR, 1974).

Surface samples were collected from May to November, 1997. MTBE was detected in 63 percent (5) of 8 samples collected at Monument Hill boat ramp at concentrations of 1 to 11 µg/L (**Table 13**). The highest value was found on September 2, 1997, after Labor Day weekend. Similar to the trend at Lake Oroville, MTBE concentrations were higher after both the Independence Day and Labor Day weekends. MTBE increased from below detection on July 3 to 3 µg/L on July 7, 1997. The increase was greater following Labor Day weekend when MTBE increased by 9 µg/L (from 2 to 11 µg/L).

In addition to MTBE, BTEX compounds were detected in samples from May 27 and October 2. Total xylene was detected in 25 percent (2) of 8 samples at concentrations of 0.7 to 2.4 µg/L. MTBE was not detected on May 27th while toluene, xylene and 1,2,4-trimethylbenzene were found at concentrations greater than the reporting level of 0.5 µg/L. MTBE, toluene, and xylene were detected on October 2nd.

Table 13. MTBE and BTEX compounds detected in surface samples from Monument Hill boat ramp in Thermalito Afterbay, 1997.
[nd, non-detectable]

Date	VOC's	µg/L
27-May-97	MTBE	nd
	Toluene	1.2
	Total xylene	2.4
	1,2,4-trimethylbenzene	0.5
3-Jul-97	MTBE	nd
7-Jul-97	MTBE	3
6-Aug-97	MTBE	nd
29-Aug-97	MTBE	2
2-Sep-97	MTBE	11
2-Oct-97	MTBE	5.0
	Toluene	0.7
	Total xylene	0.7
6-Nov-97	MTBE	1.0

Lake Del Valle

Lake Del Valle is located in Arroyo Del Valle, south of Livermore Valley. The lake provides regulatory storage for the South Bay Aqueduct, flood control for Alameda Creek, conservation of storm runoff, recreation, and fish and wildlife enhancement.

Releases from Lake Del Valle usually begin on the day after Labor Day weekend. The intake structure allows for selective releases at elevations of 690, 670, 650, 630, and 620 feet. Normal operation during autumn releases are at 690, 670 and 650 feet. When the reservoir surface is within 5 feet of a valve, that valve is closed and the next lower valve is opened. Each of the five valves has a capacity of 120 cfs. Total capacity of the inlet-outlet structure is 600 cfs. Minimum reservoir capacity at 674 feet elevation is 25,000 ac-ft.

The lake has a total volume of 77,106 ac-ft and surface area of 1,060 acres at spillway elevation. Maximum recreational capacity is 40,000 ac-ft with a surface area of 708 acres. Recreational activities allowed in the lake include fishing, swimming, and sailing. Personnel watercraft are not allowed and the maximum boat speed limit is 10 m.p.h.

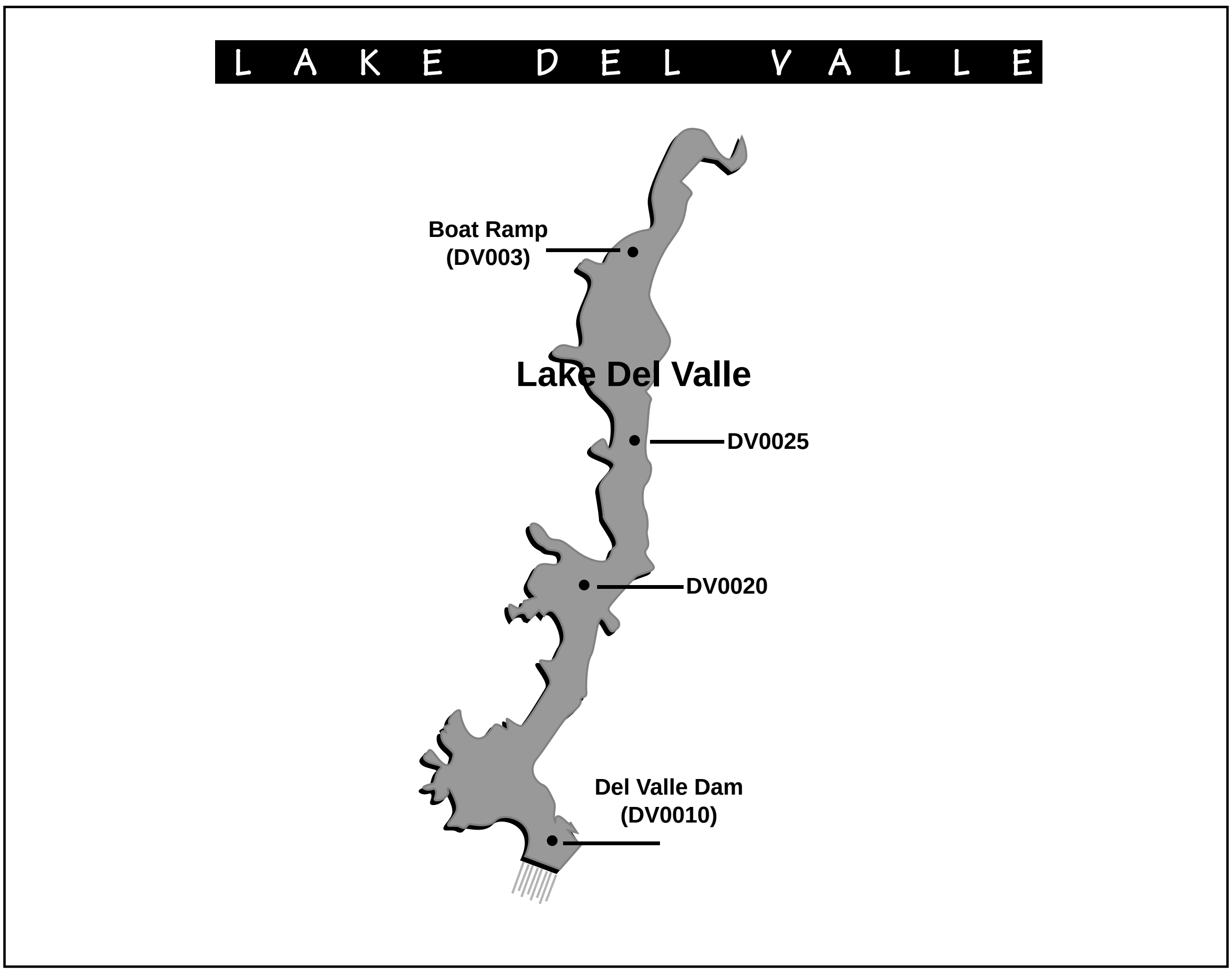

Figure 7. Map of Lake Del Valle sampling sites, 1997

Samples were collected at two sites, the Eastside Boat Launch (DV003) and Del Valle Dam (DV001) from April to December 1997. Two additional stations, DV0025 and DV002 were added in May (**Fig. 7).** Surface (0.5 m) samples were collected at the East Side Boat Launch Area (DV003); DV0025 (1.4 miles NW of DV003) and DV002 (2.3 miles NW of DV003). Surface (0.5), mid-depth (4 - 12 m) and lower depths were sampled near the Del Valle dam at station DV001. Sampling depth was dependent on the thermal structure and ranged from 4 m to 12 m for z2, and 8 m to 14 m for z3.

Thermocline depth at the beginning of the study was 5.0 m. By mid-June, the thermocline deepened to 10 m with a maximum temperature change at the thermocline of -1.7 to -2.4 °C m^{-1} (**Table 14**). In late September, the thermocline began to weaken and the maximum change decreased to -1.2 °C m^{-1}. The lake mixed and became isothermal in early December, 1997.

For most of the study, depths z2 and z3 were within the lower epilimnion and hypolimnion, respectively. However, on 22-Apr-97, both z2 and z3 were below the 5 m thermocline; and on 17-Jun-97 and 7-Jul-97, z2 and z3 were within the epilimnion.

Results

MTBE was detected in 100 percent of 13 samples at the Eastside Boat Launch (**Fig 8**). Concentrations ranged from 2.7 to 10.2 µg/L with a mean of 5.8 µg/L and median of 6.0 µg/L. Seasonally, samples from May to early July had the highest concentrations of MTBE.

Table 14. Sample and thermocline depths (m) in Lake Del Valle near dam (DV001), 1997.

Date	Sample depth (m) z1	z2	z3	Thermo-cline	Max. Δ °C/m
4/22/97	0.5	8	12	5	-1.3
5/13/97	0.5	4	8	5	-2.2
5/23/97	0.5	6	8	7	-2.3
5/27/97	0.5	6	8	8	-2.4
6/17/97	0.5	5	8	10	-1.7
7/03/97	0.5	8	12	10	-1.8
7/07/97	0.5	6	8	10	-1.8
8/29/97	0.5	8	12	10	-2.2
9/02/97	0.5	8	12	10	-2.4
9/16/97	0.5	8	12	11	-2.5
10/14/97	0.5	9	11	11	-2.6
11/24/97	0.5	12	14	13	-1.2
12/11/97	0.5	4	8	-	-0.1

At the Outlet Tower (DV001), MTBE was detected in 92 percent (24) of 26 samples from the surface (z1) and z2. MTBE did not change greatly throughout the season at DV001 with a range from below detection to 4.8 µg/L. The narrow range of MTBE was also evident in the samples collected at deeper depths. MTBE at z2 and z3 ranged from less than detection to 4.1 and 2.3 µg/L, respectively.

In the deepwater sample (z3), MTBE was detected in 54 percent (7) of 13 samples. MTBE was detected in the first 3 samples of the year (4/22, 5/13, and 5/23). Samples from z3 were taken from 1 to 3 m below the thermocline during those dates (**Table 14**). MTBE was below detection on 26-May, 4 days after the previous sample. MTBE on 17-Jun-97 was 2 µg/L, however, the sample was collected in the epilimnion, 2 m above the thermocline. MTBE in the deepwater sample was at or less than detection (1 µg/L) for the remainder of the season. At lake turnover MTBE was homogenous throughout the water column at 2 µg/L.

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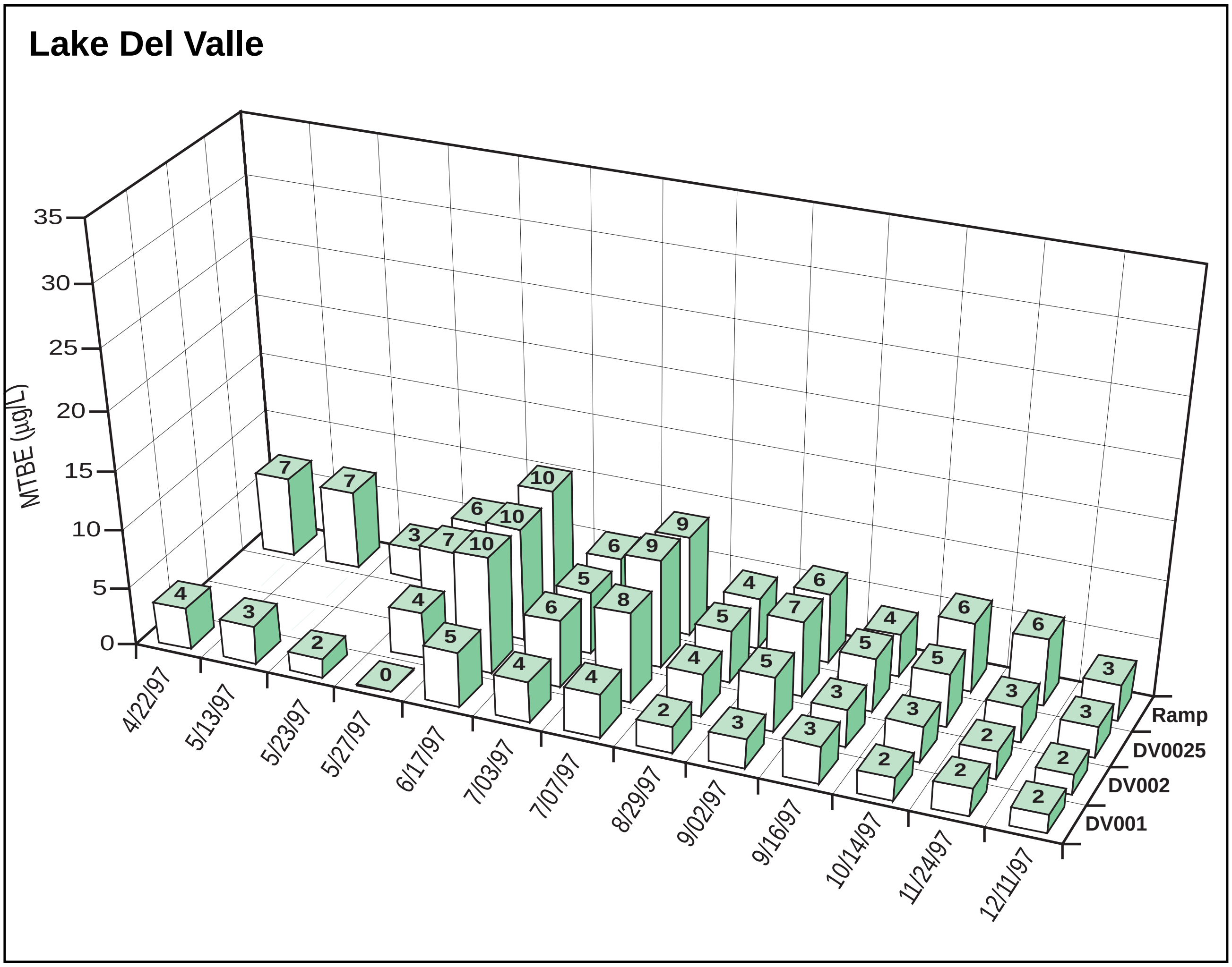


Figure 8. Surface MTBE concentrations at four sites in Lake Del Valle, 1997.

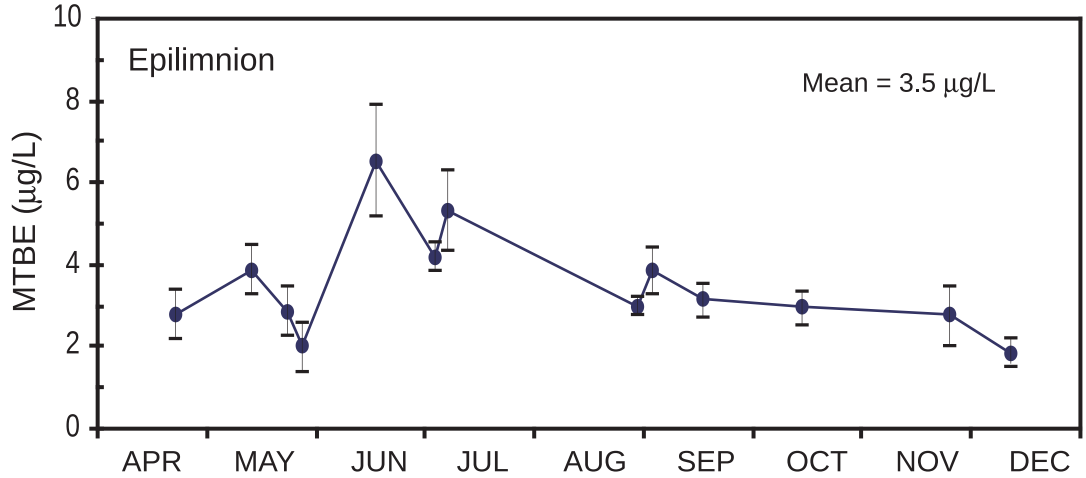


Figure 9. Seasonal changes in epilimnetic MTBE (mean ±1 SD) at Lake Del Valle, 1997. Areal weighted MTBE from four sampling sites used in calculations.

Areal weighted MTBE was calculated for Lake Del Valle based on calculations of the lake surface area and volume (**Fig. 9**). Station DV001 located near Del Valle outlet represented 61 percent of total lake volume. This station is located near the deepest portion of the lake. The other stations and percent of total lake volume represented were as follows: DV002 (18%), DV0025 (14%), and the boat ramp, DV003 (6%).

The greatest increase in epilimnetic MTBE occurred in mid-June, after Memorial Day weekend. Wholelake epilimnetic MTBE increased from 2.0 µg/L to 6.5 µg/L in a 21 day period (0.21 µg/L). The calculated mass of MTBE in the in the lake increased by 130 pounds during that period (**Fig. 10**).

Table 15. Mean MTBE (µg/L) in Lake Del Valle, 1997.
[S, surface (0.5 m); n, number of samples; S.D., standard deviation; nd, non-detectable = <1.0 µg/L]

	Depth	Mean	n	S.D.
Boat ramp				
DV003	S	5.8	13	2.1
Reservoir				
DV0025	S	5.7	10	2.4
DV002	S	4.7	10	2.5
DV001	z1	2.7	13	1.2
	z2	2.5	13	1.0
	z3	0.9	13	1.0

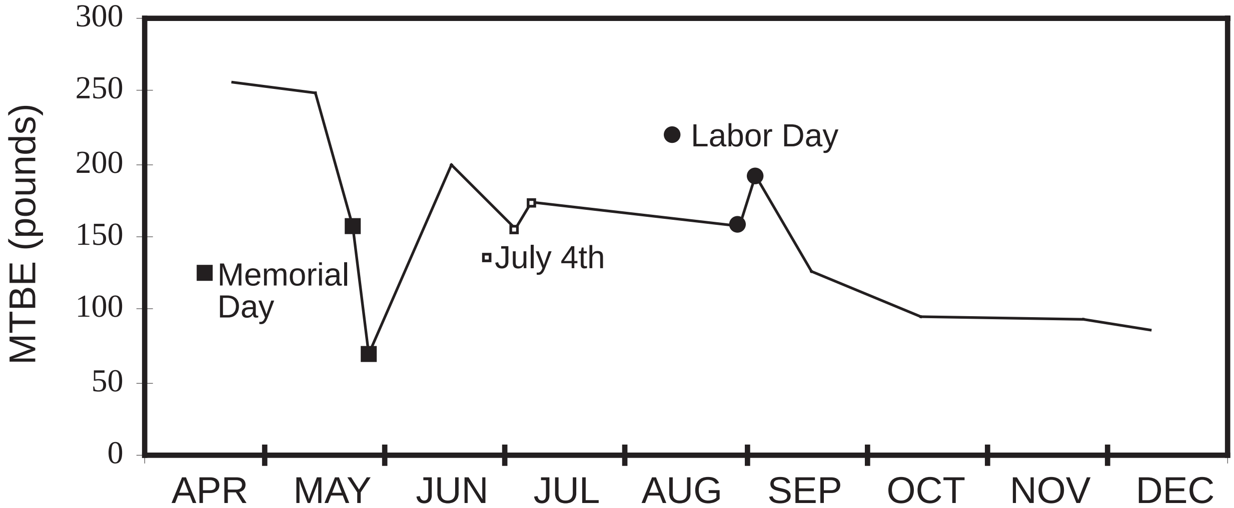


Figure 10. Seasonal changes in wholelake MTBE as pounds in Lake Del Valle, 1997. Values calculated from MTBE concentrations at four stations.

MTBE mass of 255 pounds was highest at the beginning of the survey in April. These values were calculated based on volume weighting at the four sampling stations. MTBE decreased to about 70 pounds after the Memorial Day weekend. MTBE increased dramatically to 155 pounds on 6-17-98 or at a rate of about 6 pounds/da. There was a loss in MTBE from volatilization for the remainder of the survey except during the two peak holiday weekends. MTBE increased by 18 pounds during the July 4th weekend. The change was greater on Labor Day when MTBE increased by 34 pounds from 151 to 191 pounds. After Labor Day weekend, the mass of MTBE declined to 86 pounds in December at the time of lake turnover.

Lake Del Valle

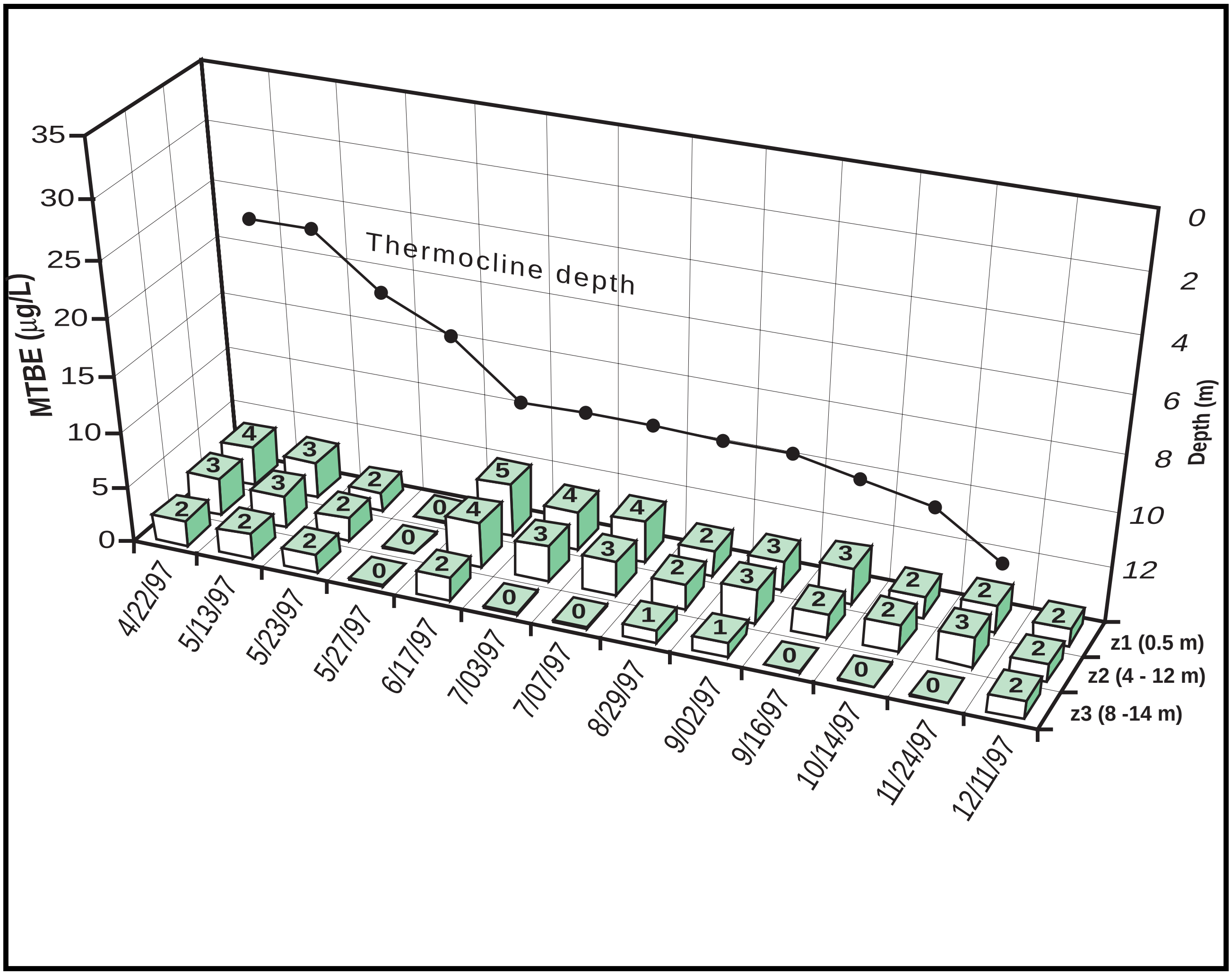


Figure 11. Thermocline depth and MTBE concentrations at three depths near dam in Lake Del Valle, 1997.

The change in MTBE over holiday weekends ranged from -2 to 4 µg/L (**Fig. 12).** The greatest increase was at the Eastside boat ramp and DV0025 where MTBE increased by 4 µg/L over Memorial Day and July 4th weekends. At Eastside boat ramp, MTBE increased by 3 µg/L during July 4th and 2 µg/L during Labor Day weekend.

The holiday weekend change in Lake Del Valle MTBE decreased with distance from the Eastside boat ramp. Mean MTBE at Eastside boat ramp (DV003) and DV0025 were nearly equal at 5.8 and 5.7 µg/L, respectively. At station DFV002, located about 1.7 miles for the boat ramp, mean MTBE declined to 4.7 µg/L. At the most distant station from the boat ramp (DV003), mean surface MTBE was 2.7 µg/L.

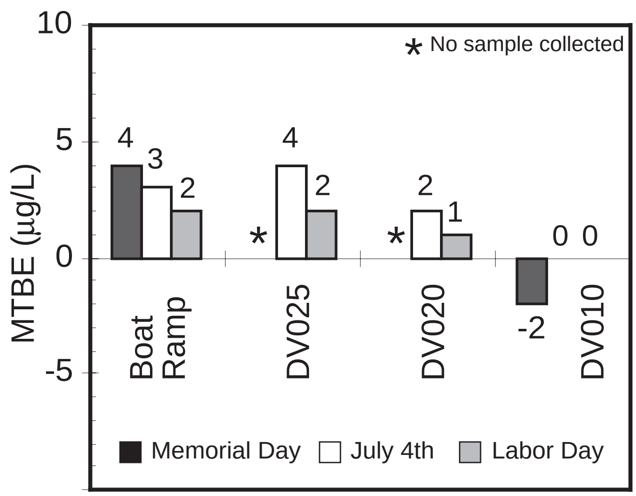


Figure 12. Change over holiday weekends in surface MTBE at Lake Del Valle.
Memorial Day = MTBE on 27-May-97 — 23-May-97
July 4th = 7-Jul-97 — 3-Jul-97;
Labor Day = 2-Sep-97 — 29-Aug-97.
Positive numbers indicates an increase in MTBE.

Table 16. Volatile organic compounds detected in Lake Del Valle, 1997.
[**, mean of 3 samples]

Date	Station	Depth (m)	VOC	µg/L
27-May-97	Boat ramp	0.5	MTBE	6.2
			Toluene	0.5
17-Jun-97	Boat ramp	0.5	MTBE	11.0
			Toluene	0.7
3-Jul-97	Boat ramp	0.5	MTBE	6.0
			Toluene	0.8
7-Jul-97	DV0025**	0.5	MTBE	9.3
			Toluene	0.8
29-Aug-97	Boat ramp	0.5	MTBE	4.1
			Toluene	0.6

BTEX compounds were detected in 31 percent (4) of 13 samples from Eastside boat ramp (**Table 16**). Toluene was detected with MTBE in all 4 samples at low concentrations of 0.5 to 0.8 µg/L. The other BTEX detection was at DV0025, the station closest to the boat ramp, where MTBE and toluene were detected together on 7-Jul-97.

MTBE Spatial Heterogeneity

At two stations in Lake Del Valle, Eastside boat ramp (DV003) and DV0025, triplicate samples were collected on 9 dates for a total of 54 samples. Each of the 3 samples was collected by individual hauls in the water sampler. Three sample VOC vials were filled quickly and the process repeated for sample B and C. The boat was allowed to drift during sample collection which took less than 5 minutes for 3 samples (9 vials). The purpose of this sampling was to quantify variability from spatial heterogeneity, sampling, transportation, and laboratory analysis.

The individual MTBE sample results, mean, and standard deviation are presented in **Table 17**. At Eastside boat ramp, standard deviation ranged from 0.4 to 1.3. One sample from 7-Jul-97 had a SD greater than 1.0. The results were similar at DV0025 where the SD was less than 1.0 on 8 of the 9 dates. Samples from 17-June-97 had a SD of 2.0. These results show the low variability between multiple samples collected at one location. A single sample appears to be sufficient to quality MTBE levels with a standard deviation less than 1.0.

Table 17. Triplicate sampling at two Lake Del Valle stations, 1997. SD, standard deviation; sample depth = 0.5 m.

	Boat ramp					Reservoir - DV0025				
Station	A	B	C	Mean	SD	A	B	C	Mean	SD
1997										
17-Jun	11.0	10.0	9.7	10.2	0.7	12.0	8.4	8.6	9.7	2.0
3-Jul	6.0	5.3	5.1	5.5	0.5	5.5	5.5	5.2	5.4	0.2
7-Jul	10.0	7.6	7.8	8.5	1.3	10.0	9.1	8.8	9.3	0.6
29-Aug	4.1	4.5	4.5	4.4	0.2	4.6	4.6	4.2	4.5	0.2
2-Sep	6.3	6.0	5.8	6.0	0.3	5.5	6.9	7.2	6.5	0.9
16-Sep	3.7	3.8	3.5	3.7	0.2	4.1	5.3	4.5	4.6	0.6
14-Oct	5.7	6.3	5.9	6.0	0.3	4.3	5.3	4.3	4.6	0.6
24-Nov	5.4	5.3	6.8	5.8	0.8	3.9	5.1	4.3	4.4	0.6
11-Dec	3.6	2.9	3.0	3.2	0.4	3.0	2.4	2.5	2.6	0.3

Table 18. Number of boater days in Lake Del Valle
Private boat data from entrance fees provided by East Bay Regional Parks.

1997	Cartop & Inflatables	Trailered boats	Total Private	Rental
April - Total	181	976	1157	
24-May			69	60
25-May			119	60
26-May			87	60
May - Total	251	1017	1268	
June - Total	243	925	1168	
4-Jul			62	60
5-Jul			76	60
6-Jul			94	60
July - Total	317	865	1182	
30-Aug			68	60
31-Aug			64	60
August - Total	206	721	927	
1-Sep			92	60
September - Total	173	496	669	
October - Total	128	511	639	
November - Total	60	488	548	
December - Total	47	457	504	

Table 18 summarizes boat usage at Lake Del Valle. Gate entrance fees are paid to the East Bay Regional Parks District. Boats are categorized into cartop and inflatable, trailered boats, and windsurf boards. Most of the cartop and inflatable, and trailered boats are powered by gasoline engines. Boats are also available for rent with 75 HP engines, adjusted for maximum speed of about 10 m.p.h. During most of summer weekends, the entire 60 boat rental fleet is checked out on a continuous daily basis.

In 1997, trailered boats made up the largest percentage of boats on the lake. Two- stroke, outboard engines in the 10 to 75 HP range are most common. The number of private boats launched at the lake increased from 1157 in April to 1268 in May. Total number of boats remained high in August at 927, then declined in the autumn to 496 boats in September.

MTBE concentrations and boat usage in the lake followed a similar trend with the highest numbers during the high use summer periods. Summer MTBE levels reached a maximum by early July and then declined for the remainder of the boating season. Boat usage in Lake Del Valle is similar during April through August with a monthly average of about 1000 boats. The number of boats using the lake declines by about one-half after Labor Day weekend to about 500 to 700 per month.

Lake Del Valle rental boat fleet comprises about 30 to 50 percent of the total number of boats utilizing the lake. The high percent of these resident boats may contribute to lower MTBE loadings than in lakes with non-resident boats. The rental boats are serviced and engines tuned-up regularly. In addition, fuel spills are minimized because the boat gas tanks are removed from the boat during filling.

San Luis Reservoir and O'Neill Forebay

San Luis Reservoir is located on the west side of the San Joaquin Valley in Merced County, 12 miles west of Los Banos. The reservoir has a capacity of 2,027,840 AF and surface area of 12,520 acre-ft (DWR, 1997b). San Luis Reservoir provides offstream storage of excess winter and spring flows diverted from the Sacramento-San Joaquin Delta. In periods of excess runoff, water is pumped into San Luis Reservoir from O'Neill Forebay via Gianelli Pumping - Generation Plant. (DWR, 1974).

O'Neill Forebay has a storage capacity of 56,430 AF and surface area of 2,700 acres (DWR, 1997b). The forebay has several inlets and outlets (**Fig. 13**). Inlets to O'Neill Forebay include the California Aqueduct and O'Neill Pumping Generation Plant which is supplied by the Delta-Mendota Canal. Gianelli Pumping - Generating Plant functions both as an inlet and outlet. The California Aqueduct serves as an outlet at Check 13.

Recreation activities at San Luis Reservoir and O'Neill Forebay include boating, sailing, water skiing, fishing, and waterfowl hunting.

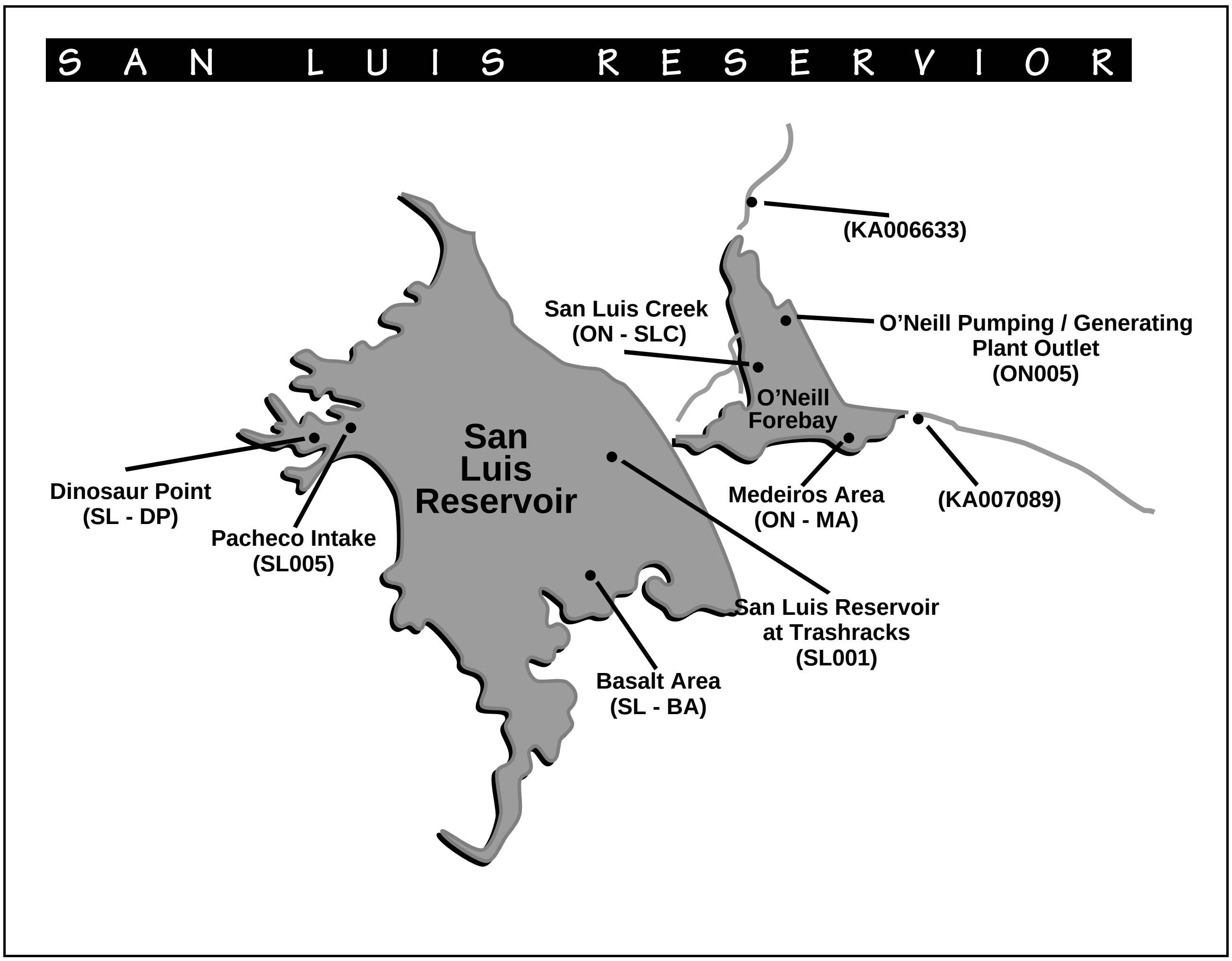


Figure 13. Map of San Luis Reservoir and O'Neill Forebay sampling sites, 1997

Table 19. Monthly MTBE as µg/L in San Luis Reservoir and O'Neill Forebay, 1997.

Station		Depth (m)	MTBE µg/L 23-May	27-May	3-Jul	7-Jul	6-Aug	14-Oct
San Luis Reservoir								
SL001	Trashracks	0.5	nd	nd	nd	nd	nd	nd
	Trashracks	8	-	nd	nd	nd	nd	nd
	Trashracks	20	-	nd	nd	nd	nd	nd
SL005	Tunnel Island	0.5	nd	nd	nd	nd	nd	nd
SL-DP	Dinosaur Point boat ramp	0.5	nd	nd	nd	nd	**2**	nd
SL-BA	Basalt Area boat ramp	0.5	nd	nd	nd	nd	nd	nd
O'Neill Forebay								
ON005	O'Neill PP outlet	0.5	nd	nd	nd	**2**	**2**	**2**
ON-SLC	San Luis Creek boat ramp	0.5	nd	nd	nd	nd	nd	nd
ON-MA	Medeiros Area boat ramp	0.5	nd	nd	nd	nd	nd	nd

nd = <1 µg/L

Dinosaur Point and Basalt Area boat ramps were sampled in San Luis Reservoir. Surface samples were collected from May to October, 1997. Three depths were sampled at the trashracks (SL001) where water from O'Neill Forebay enters the reservoir at Gianelli San Luis Pumping - Generating Plant. Samples were collected the surface (0.5 m), 8, and 20 m depths. Surface samples were also collected at the Pacheco Intake (SL005).

Results

MTBE was not detected at the trashracks (SL001) or Pacheco Intake (SL005). A total of 12 surface, 6 mid-depth, and 6 hypolimnetic samples were collected at these two stations (**Table 19**).

MTBE was also low at the boat ramps. Of the 12 surface samples collected at Dinosaur Point and Basalt Area from May to October, MTBE was detected once (2 µg/L on August 6).

MTBE in O'Neill Forebay was near or below the detection level in all samples. MTBE was not detected at the two boat ramps (San Luis Creek and Medeiros Area). At the O'Neill Pumping Generation Plant outlet (ON005), MTBE was detected in 3 of 6 samples at a concentrations of 2 µg/L (**Table 19**).

In summary, MTBE was not detected in 92 percent (48) of 52 samples from San Luis Reservoir and O'Neill Forebay. The highest MTBE value was 2 µg/L.

Pyramid Lake

Pyramid Lake is located within the Los Angeles and Los Padres National Forests on Piru Creek about 14 miles north of the town of Castaic. Pyramid Lake has volume of 171,200 af and surface area of 1,300 acres (DWR, 1997b).

Pyramid Lake is a multi-purpose facility that provides regulatory storage for Castaic Powerplant and afterbay for William E. Warne Powerplant, emergency storage for water deliveries form the West Branch. Recreational activities include camping, picnicking, boating, swimming, and water skiing.

Boat launching ramps are located at Emigrant Landing, Serrano and Vaquero (**Fig. 14**). Surface samples (0.5 m) were collected from June to early November, 1997. Three depths were sampled at the index station at Tunnel Inlet near Pyramid Dam (**Table 20**).

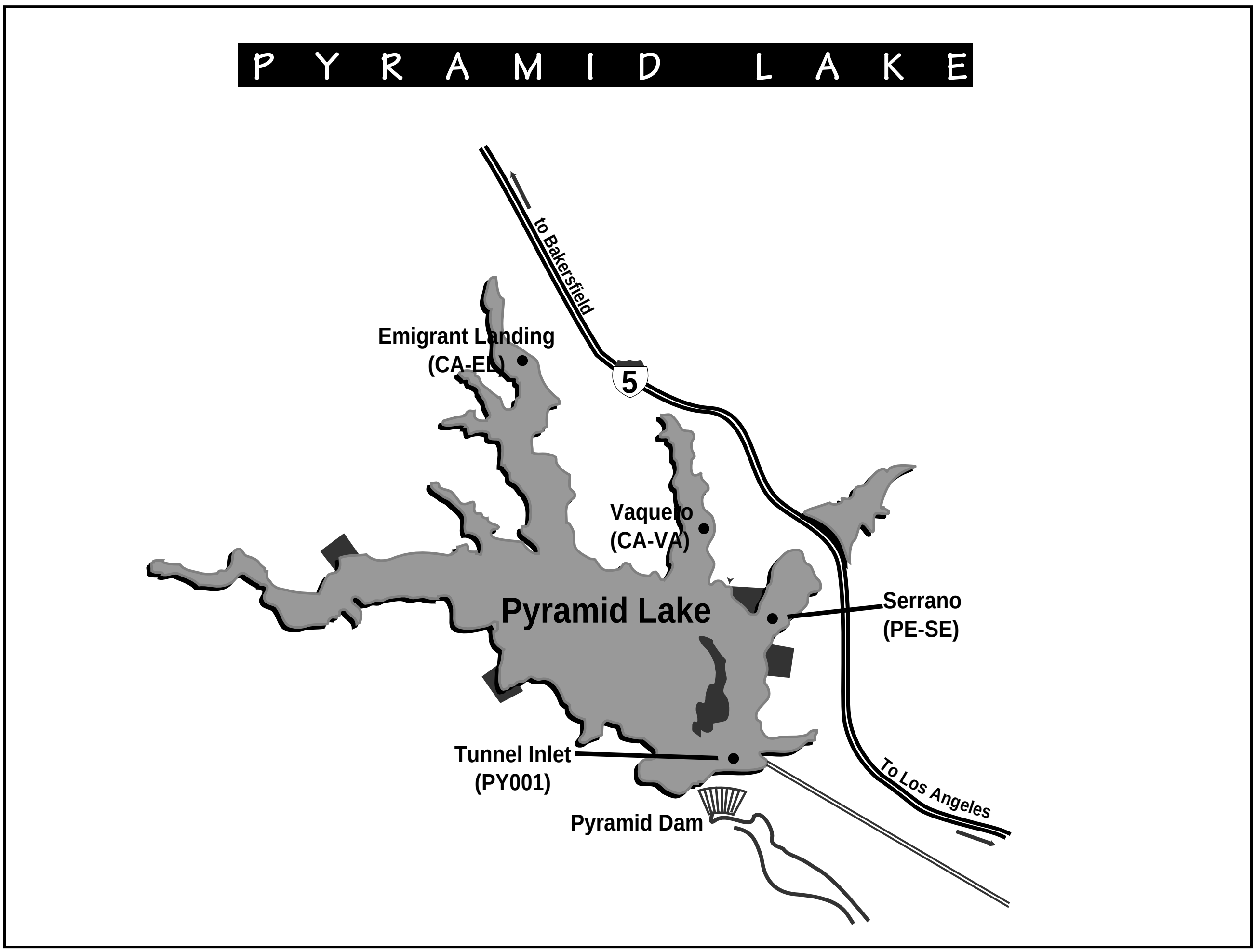


Figure 14. Map of Pyramid Lake sampling sites, 1997

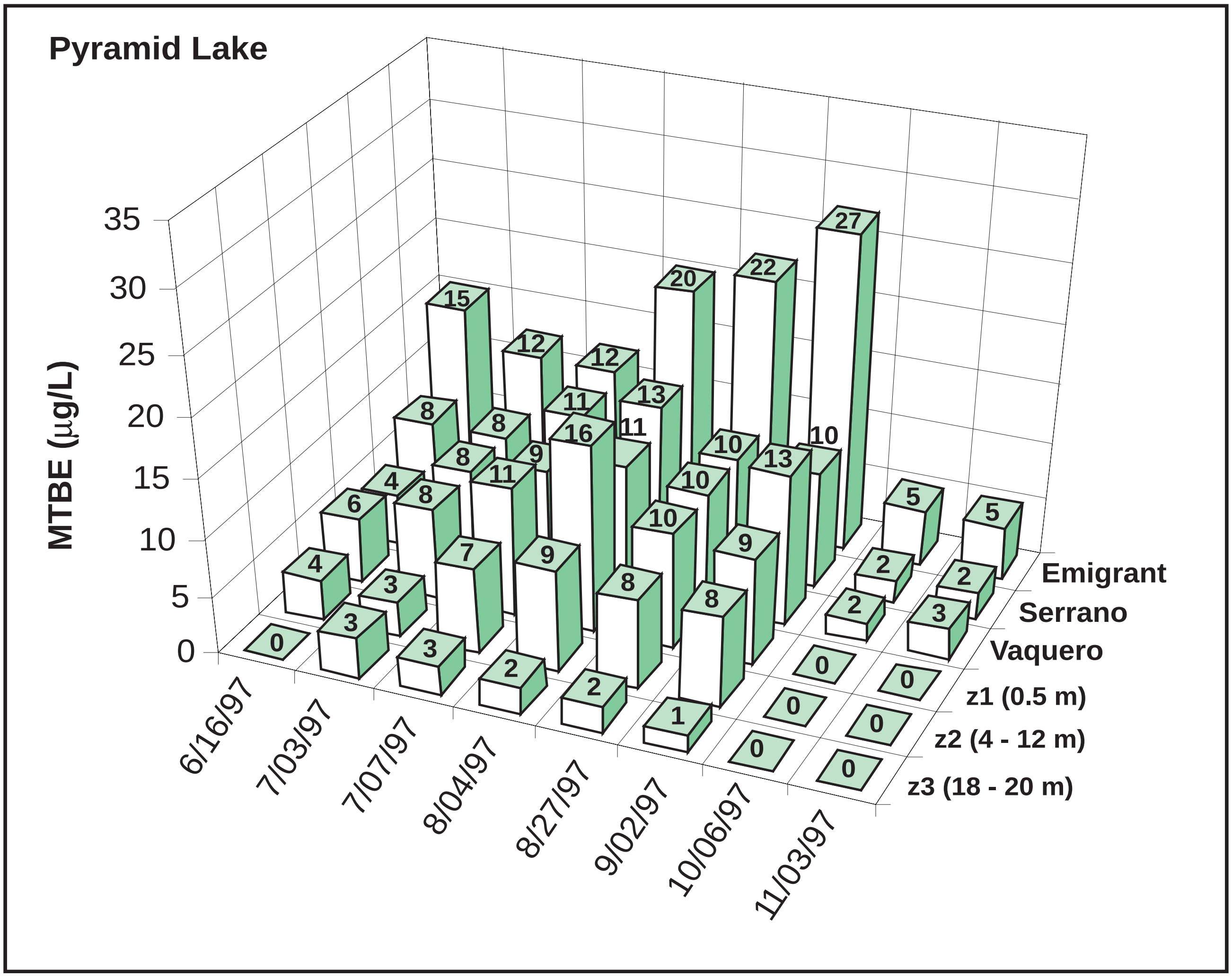


Figure 15. MTBE concentrations at Tunnel Inlet and Emigrant, Serrano, and Vaquero boat launching ramps in Pyramid Lake, 1997.

Table 20. Sample and thermocline depth (m) at Tunnel Inlet in Pyramid Lake, 1997.

	Sample depth (m)			Thermo-	Max.
Date	**z1**	**z2**	**z3**	**cline**	**Δ °C/m**
6/16/97	0.5	10	20	14.0	-0.4
7/03/97	0.5	12	20	5.5	-0.4
7/07/97	0.5	4	20	4.0	-0.3
8/04/97	0.5	7	20	8.0	-0.3
8/27/97	0.5	9	18	-	-0.1
9/02/97	0.5	10	20	-	-0.1
10/06/97	0.5	9	18	-	-0.1
11/03/97	0.5	10	20	-	-0.1

Pyramid Lake was weakly stratified during the summer with the thermocline not clearly defined. Maximum temperature change in Pyramid Lake was -0.3 to -0.4 °C m^{-1} (**Table 20**). In comparison, maximum temperature change with depth during the stratified summer period was -1.4 to -1.6 °C m^{-1} in Silverwood Lake. High volumes of water moving through the reservoir prevent thermal stratification from establishing in the summer.

Table 21. Mean MTBE (µg/L) in Pyramid Lake, 1997.
[S, surface (0.5 m); n, number of samples; S.D., standard deviation]

	Depth	Mean	n	S.D.
Boat ramps				
Emigrant	S	14.7	8	8.0
Serrano	S	8.0	8	4.0
Vaquero	S	7.5	8	4.1
Mean		10.0	24	6.4
Reservoir				
Tunnel Inlet	z1	7.4	8	5.5
	z2	4.8	8	3.6
(PY001)	z3	1.5	8	1.3

MTBE was detected in 75 percent (6) of 8 surface samples from the Tunnel Inlet. When detected, MTBE ranged in concentration from 9 to 16 µg/L (**Fig. 15**) with a mean of 7.4 µg/L (**Table 21**). MTBE at Tunnel Inlet was below detection at all depths in October and November.

MTBE at the lower epilimnion (4 -12 m) was detected in the same percentage of samples (75 percent) as the surface. Concentrations were lower than the surface and ranged from 3 µg/L to 9 µg/L (mean = 4.8 µg/L). Maximum concentrations were found during August to early September.

MTBE was lowest in the deepwater samples (z3) and detected in 5 of 8 samples (63 percent) at concentrations from 1 to 3 µg/L with a mean of 1.5 µg/L (**Table 21**). Since the lake did not develop a well defined thermocline in the summer, depth z3 was within the freely circulating portion of the lake and not thermally isolated from the epilimnion.

MTBE at the three boat ramps was high during the summer reaching a maximum of 27 µg/L on 02-Sep-97 at Emigrant Landing. All samples from the Pyramid Lake boat ramps had MTBE levels greater than 2 µg/L. Emigrant Landing had the highest MTBE with mean MTBE of 14.7 (n=8), followed by Serrano and Vaquero at 8 and 7.5 µg/L, respectively (**Table 21**). The seasonal pattern of MTBE was similar at the launching ramps and reservoir stations where MTBE increased from early June to a maximum in early September, after Labor Day weekend. MTBE declined in the autumn to 2 to 3 µg/L at Serrano and Vaquero, and to 5 µg/L at Emigrant Landing.

Post-holiday changes in surface MTBE concentrations were highly variable between stations (**Fig. 16**). At the Tunnel Inlet and Serrano, post-July 4th MTBE was 3 µg/L higher than pre-holiday values. The increase was less at Vaquero and Emigrant Landing where MTBE changed by 1 and 0 µg/L, respectively.

In contrast to July 4th, the greatest post-Labor Day change in MTBE was found at Vaquero and Emigrant where MTBE increased by 3 µg/L and 5 µg/L, respectively. Over the same period, MTBE declined by 1 µg/L at Tunnel Inlet. At Serrano, MTBE did not change from the pre-Labor Day value of 10 µg/L.

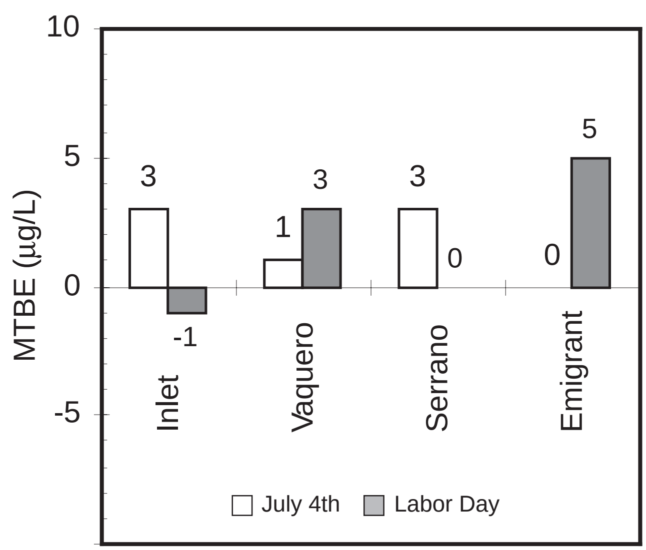


Figure 16. Change over holiday weekends in surface MTBE at Pyramid Lake;
July 4th = MTBE on 7-Jul-97 — 3-Jul-97;
Labor Day = 2-Sep-97 — 29-Aug-97.
Positive values indicate an increase.

Table 22. MTBE and BTEX compounds detected in Pyramid Lake, 1997.

Date	Station	Depth (m)	VOC	µg/L
3-Jul-97	Emigrant Landing	0.5	MTBE	12.0
			Total xylene	0.8
27-Aug-97	Emigrant Landing	0.5	MTBE	22.0
			Total xylene	2.2
			1,2,4-Trimethylbenzene	0.6
			Toluene	1.4
2-Sep-97	Emigrant Landing	0.5	MTBE	27.0
			Total xylene	1.8
			1,2,4-Trimethylbenzene	0.6
			Toluene	1.3
3-Nov-97	Emigrant Landing	0.5	MTBE	5.0
			Total xylene	0.7
			Toluene	0.8

MTBE and BTEX compounds were detected in 50 percent (4) of 8 samples from Emigrant Landing boat ramp. BTEX compounds were not detected at Serrano or Vaquero boat ramps or at the Tunnel Inlet. Including all samples collected in Pyramid Lake, BTEX compounds and MTBE together were detected in 8 percent (4) of 48 samples.

Total xylene was the most frequently detected BTEX compound at Emigrant Landing. When detected, total xylene ranged in concentration from 0.7 to 2.2 µg/L. MTBE was in the range of 5 to 27 µg/L when detected together with BTEX compounds. Toluene, total xylene, and 1,2,4-trimethylbenzene were detected together in 25 percent (2) of 8 samples from Emigrant Landing. When detected, toluene ranged from 0.8 µg/L to 1.4 µg/L and 1,2,4-trimethylbenzene was 0.6 µg/L (**Table 22**).

There does not appear to be a relationship between the presence of BTEX compounds and MTBE concentration. At Emigrant Landing, BTEX compounds were detected at the highest MTBE concentrations of 22 and 27 µg/L. However, on 03-Nov-97 BTEX compounds were detected when MTBE was at the lowest observed value of 5 µg/L.

Castaic Lake

Castaic Lake is located on the confluence of Castaic Creek and Elizabeth Lake Canyon Creek, about 45 miles northwest of Los Angeles. Castaic Lake was built to provide emergency storage in the event of shutdown of the California Aqueduct to the north, act as a regulatory storage facility for deliveries during normal operation, and provide recreational development and fish and wildlife enhancement (DWR, 1974.

The lake has a capacity of 323,700 af and surface area of 2,240 acres (DWR, 1997b). Castaic Lake is roughly V-shaped with the west arm designated for water-skiing and fast boating (**Fig. 17)**. The east arm is reserved for fishing, sailing, and slow boating.

Surface samples were collected at the East boat ramp in the left abutment and the West ramp from June to November, 1997. Three depths were sampled at the Castaic Lake outlet tower, CA001 (**Table 23**).

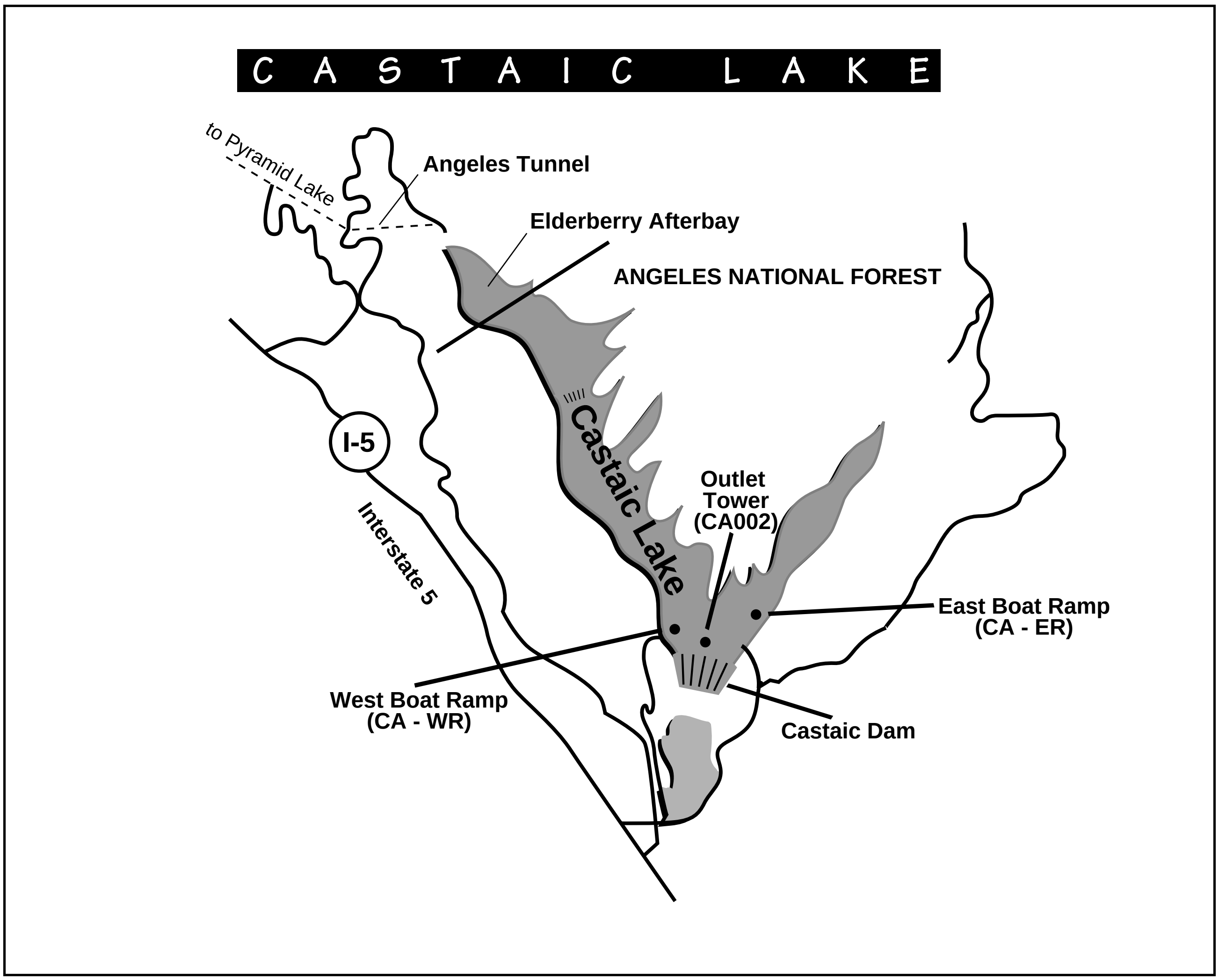


Figure 17. Map of Castaic Lake sampling sites, 1997

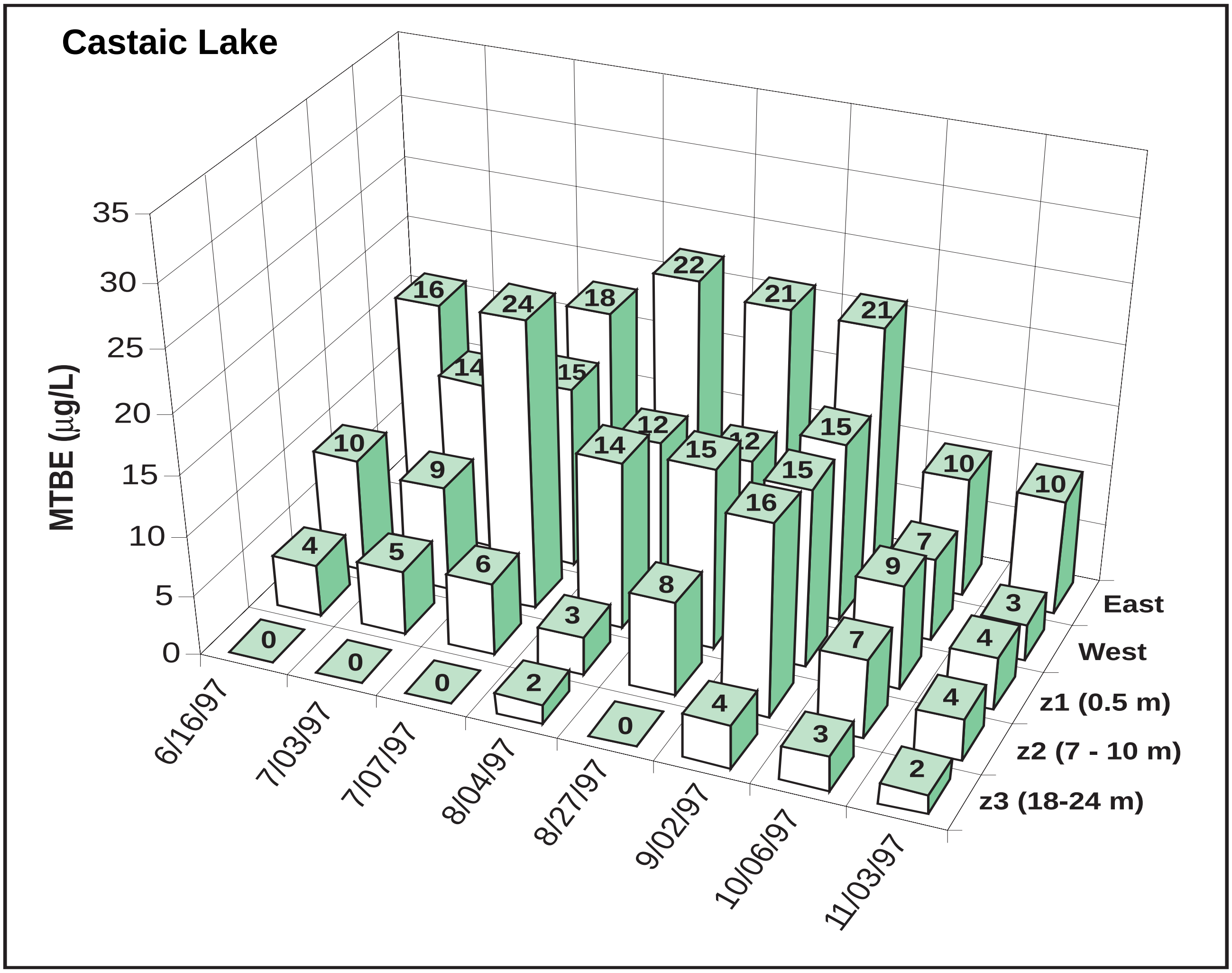


Figure 18. MTBE concentrations at east and west boat launching ramps and at the outlet tower (CA002) in Castaic Lake, 1997.

The thermocline in Castaic Lake was developed by mid-June at about 8 m depth. During the June to September stratified period, the thermocline ranged in depth from 8 to 12 m. By early October the thermal discontinuity had decreased to -0.6°C m^{-1} and the thermocline became undefined (**Table 23**).

The mid-depth sample (z2) was collected in the lower epilimnion except on 4-Aug-97 when it was below the 8 m thermocline. All deepwater samples (z3) were collected in the hypolimnion.

Table 23. Sample and thermocline depth (m) in Castaic Lake at the outlet tower, 1997.

	Sample depth (m)			Thermo-	Max.
Date	z1	z2	z3	cline	Δ °C/m
6/16/97	0.5	8	20	8	-0.7
7/03/97	0.5	7	20	9	-1.5
7/07/97	0.5	7	20	10	-1.4
8/04/97	0.5	10	24	8	-1.8
8/27/97	0.5	7	18	11	-1.6
9/02/97	0.5	7	20	12	-0.9
10/06/97	0.5	7	18	-	-0.6
11/03/97	0.5	10	20	-	-0.1

MTBE was detected in 100 percent of the 31 samples from the East and West boat ramps, and Outlet Tower surface and mid-depth (z2) samples **(Fig. 18)**.

MTBE at the East side boat ramp ranged from 9.7 to 22.0 µg/L with a mean of 16.2 (n=8). MTBE was highest during August and early September when concentrations were greater than 20 µg/L. The left (East) abutment boat ramp has an 18-lane boat launch area compared to a 6-lane ramp at the West (right) side.

MTBE concentrations at West side boat ramp were lower than at East side. MTBE ranged from 3.1 to 15.0 µg/L with a mean of 11.1 (n=7). MTBE was highest during early July and lowest in October and November at the end of the boating season.

At the Outlet tower, surface MTBE ranged from 4.4 to 24 µg/L with a mean of 12.4 µg/L (n=8). The highest value of 24 µg/L was detected on 7-Jul-97 after the July 4th weekend. Seasonally, MTBE was highest during the July to early September.

Samples collected from the lower epilimnion at 7 to 10 m had a range in MTBE of 3.3 to 16.0 µg/L with a mean of 6.6 µg/L (n=8). Most of the samples were in the range of 4 to 8 µg/L except the 2-Sep-97 sample (16 µg/L). Mean MTBE decreased with depth from 12.4 µg/L at the surface to 7 µg/L at mid-depth and 1.3 at z3.

MTBE was detected in 50 percent (4) of 8 samples from the hypolimnion (z3) at concentrations of 2 to 4 µg/L. The highest hypolimnetic MTBE concentration of 4 µg/L was found on 2-Sep-97 when the lake stratification was beginning to break down.

BTEX compounds were detected in 36 percent (14) of 39 samples (boat ramp and reservoir) from Castaic Lake. Of the 8 reservoirs examined, Castaic Lake had the highest percentage of samples in this study with detectable BTEX concentrations.

At East side boat ramp, MTBE, total xylene and toluene together were detected in 88 percent (7) of 8 samples. When detected, toluene and total xylene concentrations ranged from 1.0 to 3.7 µg/L and 0.6 to 6.0 µg/L, respectively (**Table 25**). Ethylbenzene was detected in 3 of 8 samples at concentrations of 0.5 to 0.7 µg/L. Other compounds detected and (number of detections) at East side boat ramp included: Benzene (1); 1,2,-4 Trimethylbenzene (3); and 1,3,5- Trimethylbenzene (1).

BTEX compounds were detected in a lower percentage (29%) of the samples (2 of 7) from the West side boat ramp. MTBE, total xylene, and toluene were detected in two samples. In addition, 1,2,-4 Trimethylbenzene was detected in the one sample at a concentration of 0.6 µg/L.

At the outlet tower, MTBE and BTEX compounds were detected in 3 of 8 surface samples. Total xylene and toluene together were detected in the 3 samples at concentrations of 0.6 to 2.8 µg/L (xylene) and 0.9 to 1.9 µg/L (toluene). Benzene, and 1,2,-4 Trimethylbenzene were detected in 1 of 8 samples (13%) from the outlet tower.

Table 24. Mean MTBE (µg/L) in Castaic Lake, 1997.

[S, surface (0.5 m); n, number of samples; S.D., standard deviation]

	Depth	Mean	n	S.D.
Boat ramps				
East	S	16.2	8	5.1
West	S	11.1	7	4.5
Mean		13.8	15	5.3
Reservoir				
Outlet tower	z1	12.4	8	6.0
	z2	6.6	8	4.1
(CA001)	z3	1.3	8	1.5

Table 25. MTBE and BTEX compounds detected in Castaic Lake, 1997.

Date	Station	Depth (m)	VOC's	µg/L
16-Jun-97	East side boat ramp	0.5	MTBE	16.0
			Total xylene	4.2
			Toluene	3.3
			Ethylbenzene	0.5
7-Jul-97	East side boat ramp	0.5	MTBE	18.0
			Total xylene	1.7
			Toluene	1.4
4-Aug-97	Outlet tower	0.5	MTBE	14.0
			Total xylene	2.8
			1,2,4-Trimethylbenzene	0.6
			Toluene	1.3
	East side boat ramp	0.5	MTBE	22.0
			Total xylene	6.0
			Bromobenzene	1.1
			1,3,5-Trimethylbenzene	0.7
			1,2,4-Trimethylbenzene	1.5
			Benzene	0.9
			Toluene	3.7
			Ethylbenzene	0.7
	West side boat ramp	0.5	MTBE	12.0
			Total xylene	2.5
			1,2,4-Trimethylbenzene	0.6
			Toluene	1.2
27-Aug-97	East side boat ramp	0.5	MTBE	21.0
			Total xylene	2.2
			1,2,4-Trimethylbenzene	0.5
			Toluene	1.6
2-Sep-97	Outlet tower	0.5	MTBE	15.0
			Total xylene	2.1
			Toluene	1.9
			Benzene	0.5
		7.5	MTBE	16.0
			Total xylene	1.9
			Toluene	1.7
	East side boat ramp	0.5	MTBE	21.0
			Total xylene	4.3
			1,2,4-Trimethylbenzene	1.0
			Toluene	3.7
			Benzene	0.8
			Ethylbenzene	0.7
	West side boat ramp	0.5	MTBE	15.0
			Total xylene	1.6
			Toluene	1.5
6-Oct-97	Outlet tower	0.5	MTBE	9.0
			Total xylene	0.6
			Toluene	0.9
		7.5	MTBE	7.0
			Toluene	0.5
	East side boat ramp	0.5	MTBE	10.0
			Total xylene	0.6
			Toluene	1.0
3-Nov-97	East side boat ramp	0.5	MTBE	10.0
			Total xylene	1.8
			1,2,4-Trimethylbenzene	0.5
			Toluene	1.0

MTBE greatly increased over the July 4th weekend at the Outlet tower from a pre-holiday concentration of 9 to 24 µg/L on 7-Jul-97 **(Fig 19**). The increase was less dramatic at the East and West side boat ramps where over the July 4th weekend, MTBE increased by 1 µg/L and 6 µg/L, respectively

MTBE did not change substantially over Labor Day weekend at the three stations. At the Outlet Tower and East side boat ramp, pre- and post-holiday MTBE were equal. MTBE at West side boat ramp increased by 3 µg/L over that holiday period.

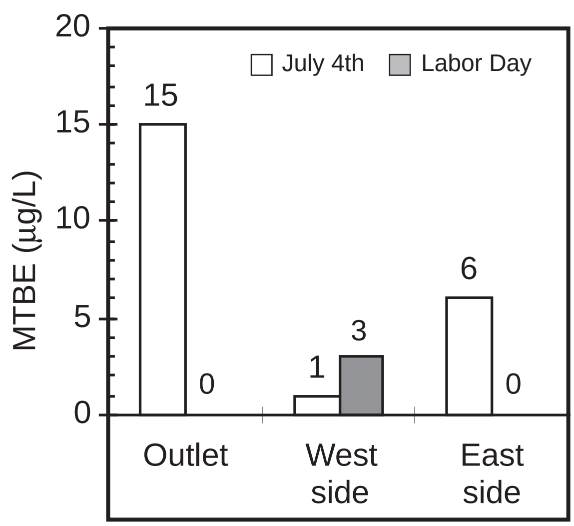


Figure 19. Change over holiday weekends in surface MTBE (µg/L) at Castaic Lake;
July 4th = MTBE on 7-Jul-97 — 3-Jul-97;
Labor Day = 2-Sep-97 — 29-Aug-97.
Positive values indicate an increase.

Silverwood Lake

Silverwood Lake and Cedar Springs Dam are located within the San Bernardino National Forest, on the West Fork of the Mojave River. The reservoir drainage area covers 34 square miles. Silverwood Lake is a multipurpose project serving as a main water source for the water agencies serving the surrounding mountain and desert communities. In addition it provides recreation such as boating, camping, picnicking, water skiing, fishing, and swimming. The reservoir also insures continuity of discharge through Devil Canyon Powerplant.

Silverwood Lake has a capacity of 74,970 af, surface area of 980 acres, and a shoreline of 13 miles. Silverwood has the smallest volume of the four southern Reservoirs examined.

The reservoir is supplied with State Water Project water from the Mojave Siphon which terminates at the inlet structure on the left abutment of the dam (DWR, 1974). The outlet works and spillway were constructed on the left abutment of Cedar Springs Dam.

Silverwood Lake was sampled from May to November 1997. Surface samples from (0.5 m) were collected at Sawpit Boat Ramp, located in the southwest arm of the reservoir. MTBE samples were collected from three depths (**Table 26**) at the San Bernardino Tunnel in the southern portion of the reservoir (**Fig. 20**).

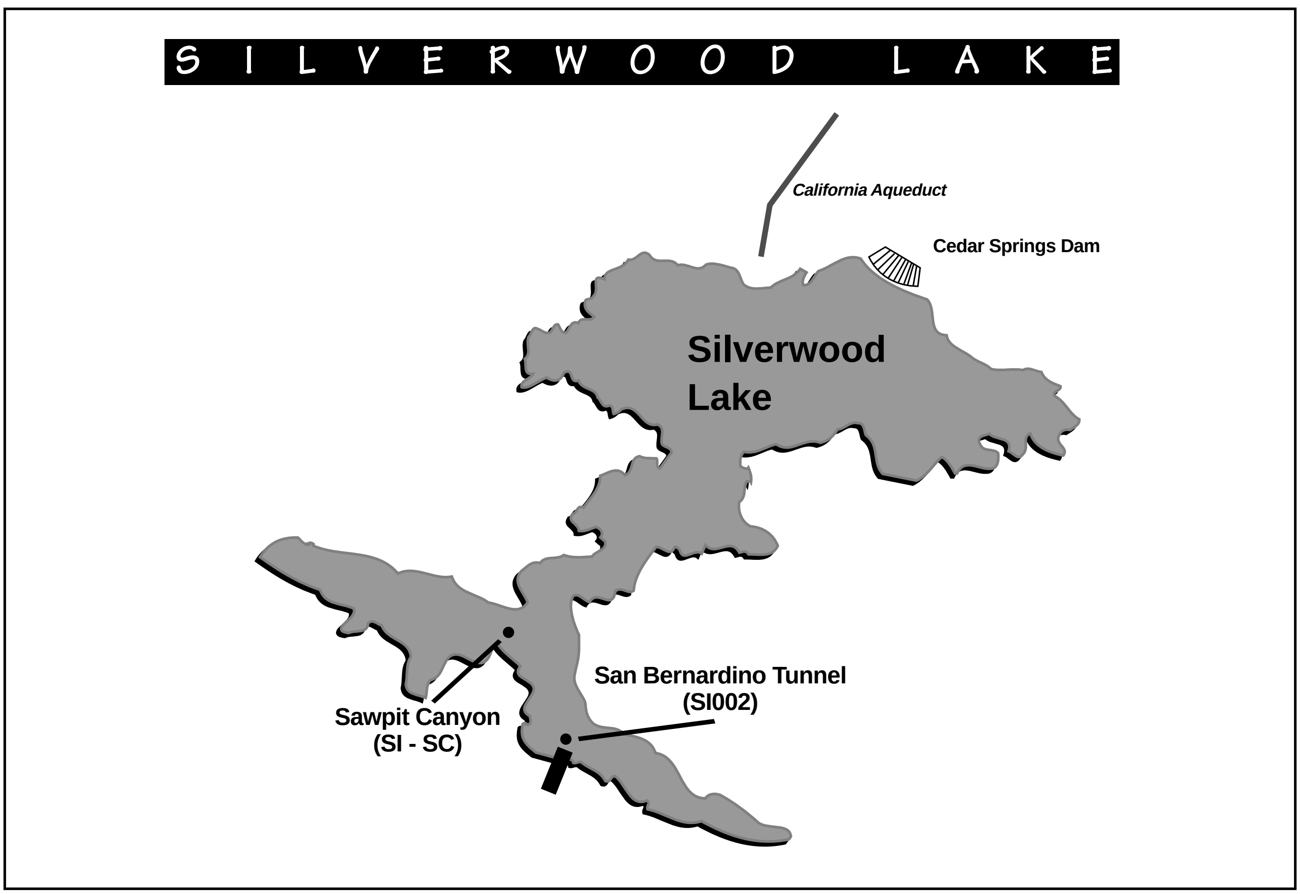


Figure 20. Map of Silverwood Lake sampling sites, 1997

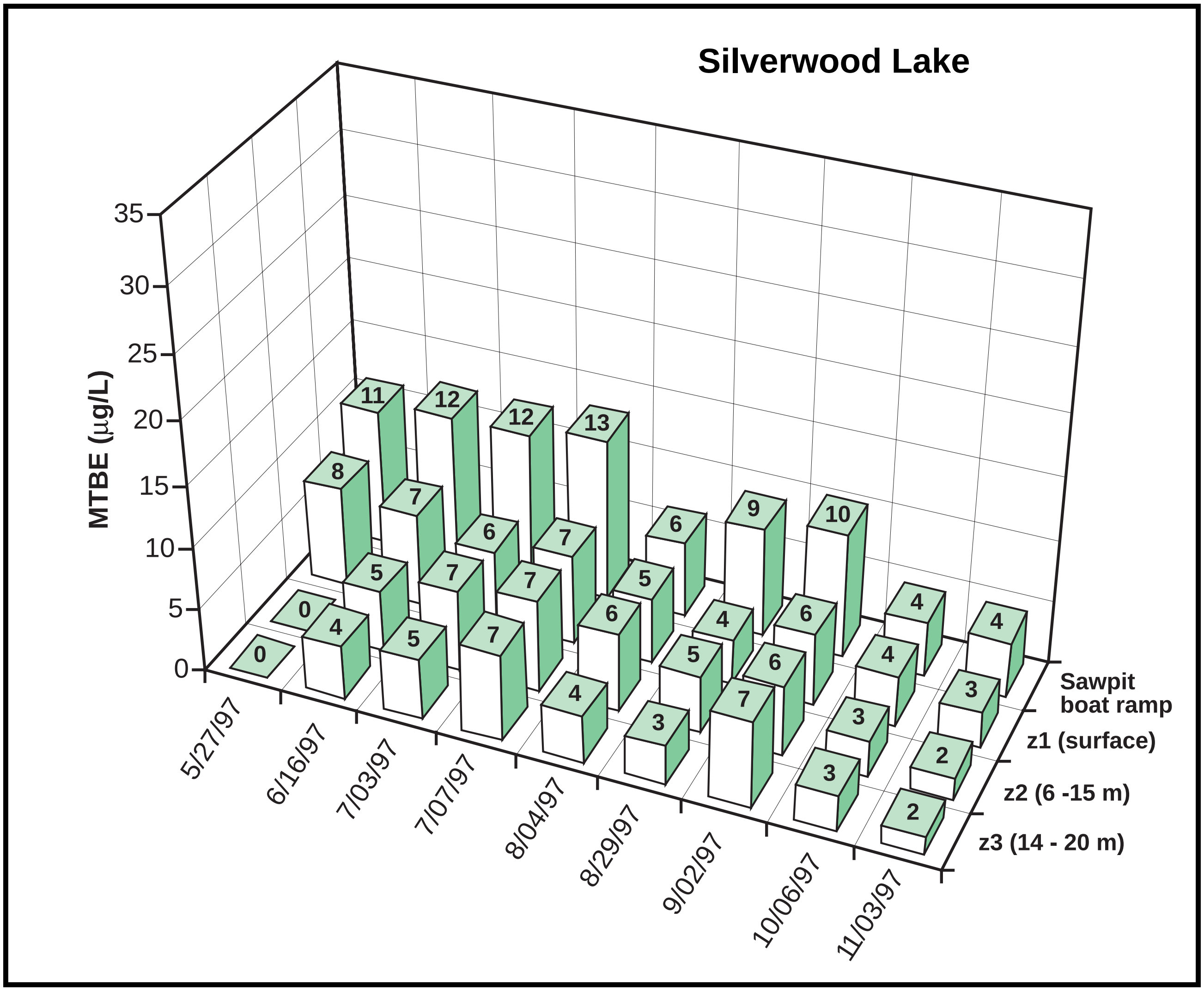


Figure 21. MTBE concentrations at Sawpit Canyon boat ramp (SI-SC) and three depths at San Bernardino Tunnel (SI002) in Silverwood Lake, 1997.

Table 26. Sample and thermocline depth (m) in Silverwood Lake at the San Bernardino Tunnel.

	Sample depth (m)			Thermo-	Max.
Date	z1	z2	z3	cline	Δ °C/m
5/27/97	0.5	10	20	20	-1.4
6/16/97	0.5	10	20	22	-1.4
7/03/97	0.5	15	20	26	-1.6
7/07/97	0.5	15	20	26	-1.6
8/04/97	0.5	10	20	30	-0.9
8/29/97	0.5	6	15	-	-0.1
9/02/97	0.5	6	15	-	-0.1
10/06/97	0.5	8	14	-	-0.1
11/03/97	0.5	8	20	-	-0.1

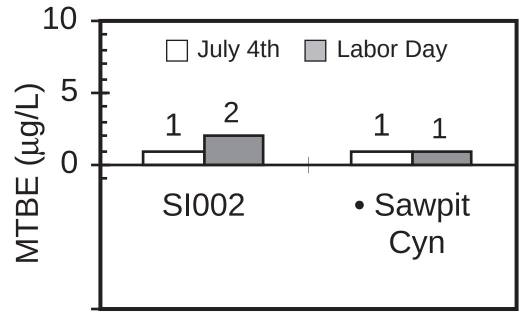
Sampling depths and thermal structure.

Silverwood Lake was stratified from May to July with the thermocline at 20 to 26 m (**Table 26**). Thermal structure began to weaken in early August with the thermocline dropping to 30 m with a maximum temperature change of -0.9 °C/m. During the stratified period, a temperature change of -1.4° to -1.6° C/m was found across the thermocline. The lake was not thermally stratified from late August through the remainder of the sampling period in November. When stratified, all samples were collected in the epilimnion, above the thermocline except on 27-May-97 when z3 was at 20m.

Table 27. Mean MTBE (µg/L) in Silverwood Lake, 1997.
[S, surface (0.5 m) ; n, number of samples; S.D., standard deviation; nd, non-detectable).

	Depth	Mean	n	S.D.
Boat ramp				
Sawpit Canyon	S	9.1	9	3.3
Reservoir				
SI002	z1	5.6	9	1.8
	z2	4.4	9	2.4
	z3	3.8	9	2.3

Figure 22. Change over holiday weekends in surface MTBE at Silverwood Lake;
July 4th = MTBE on 7-Jul-97 — 3-Jul-97;
Labor Day = 2-Sep-97 — 29-Aug-97.
Positive values indicate an increase.



MTBE was detected in all (n=8) surface samples collected at the San Bernardino Intake at concentrations of 3 to 8 µg/L with a mean of 5.6 µg/L (F**ig 21**). The highest values were found during May to July.

MTBE concentrations were relatively homogenous throughout the epilimnion during the summer. Concentrations at the 20 m depth were within 2 to 3 µg/L of the surface samples.

MTBE was detected in 89 percent (8) of 9 samples collected at z2 (6 to 12 m) at concentrations of 2 to 7 µg/L with a mean of 4.4 µg/L. Samples at z2 were collected within the mid-epilimnion during the May to early August period of thermal stratification.

At the deepwater sampling station of 14 to 20 m (z3), MTBE was also detected in 89 percent (8) of 9 samples at concentrations of 2 to 7 µg/L with as mean of 3.8 µg/L. These samples were collected in the lower epilimnion during the stratified period. Prior to lake destratification, MTBE concentrations of 7 µg/L were detected at a depth of 20 m on 7-Jul-97.

Pre- and post holiday changes in MTBE were small at the San Bernardino Tunnel and Sawpit Canyon boat ramp (**Fig. 22**). Following the July 4th weekend, MTBE increased by 1 µg/L at those two stations. The results were similar following Labor Day where MTBE increased by 2 µg/L and 1 µg/L at SI002 and Sawpit Canyon, respectively.

Table 28. MTBE and BTEX compounds detected in Silverwood Lake, 1997.

Date	Station	Depth (m)	VOC's	µg/L
27-May-97	Sawpit Canyon boat ramp	0.5	MTBE	11.0
			Total xylene	2.3
			1,2,4-Trimethylbenzene	0.7
			Toluene	1.5
16-Jun-97	Sawpit Canyon boat ramp	0.5	MTBE	12.0
			Total xylene	2.8
			1,2,4-Trimethylbenzene	0.6
			Toluene	2.6
3-Jul-97	Sawpit Canyon boat ramp	0.5	MTBE	12.0
			Total xylene	2.9
			1,2,4-Trimethylbenzene	0.6
			Toluene	2.5
7-Jul-97	Sawpit Canyon boat ramp	0.5	MTBE	13.0
			Total xylene	2.1
			1,2,4-Trimethylbenzene	0.5
			Toluene	1.8
4-Aug-97	Sawpit Canyon boat ramp	0.5	MTBE	6.0
			Total xylene	1.8
			1,2,4-Trimethylbenzene	0.5
			Toluene	1.3
29-Aug-97	Sawpit Canyon boat ramp	0.5	MTBE	9.0
			Total xylene	2.3
			1,2,4-Trimethylbenzene	0.7
			Toluene	1.7
2-Sep-97	Sawpit Canyon boat ramp	0.5	MTBE	10.0
			Total xylene	2.4
			1,2,4-Trimethylbenzene	0.6
			Toluene	2.0
3-Nov-97	Sawpit Canyon boat ramp	0.5	MTBE	4.0
			Total xylene	1.2
			Toluene	1.2

Eighty nine percent (8) of 9 samples from Sawpit Canyon boat ramp had detectable concentrations of both MTBE and BTEX compounds. Total xylene and toluene were the most frequently detected BTEX compounds at Sawpit. When detected, concentrations of total xylene and toluene ranged from 1.2 to 2.9 µg/L and 1.2 to 2.6 µg/L, respectively (**Table 28**). In 78 percent (7) of 9 samples, 1,2,4-Trimethylbenzene was detected at concentrations from 0.5 to 0.7 µg/L. All three BTEX compounds (total xylene, toluene, and 1,2,4-Trimethylbenzene) were found together in 7 of 9 samples from Sawpit Canyon.

BTEX compounds were detected in all samples from Sawpit Canyon except on 6-Oct-97 when only MTBE was detected. BTEX compounds were not detected in any samples from the San Bernardino Tunnel. Of the 36 samples collected at Pyramid Lake, MTBE and BTEX compounds were detected together in 22 percent (8) of the samples.

Lake Perris

Lake Perris is the terminal storage facility of the State Water Project, located in northwestern Riverside County about 65 miles east of Los Angeles. Completed in 1974. Lake Perris has a gross storage capacity of 131,450 ac-ft and surface area of 2,320 ac. The lake is a multi-purpose facility providing water supply, recreation, and fish and wildlife enhancement. Recreational activities include power boating, water-skiing, fishing, and swimming.

Monthly samples were collected from June to November, 1997. Surface (0.5 m) samples were collected at the boat ramp (PE-BR) and three depths were sampled at the outlet, PE002 (**Fig. 23**). Outlet samples were taken from the surface, z1, 0.5m; z2, 8 to 10 m; and z3, 8 to 16 m **(Table 29).**

The thermocline in Lake Perris began to form in late June and by 7-Jul-97 it was established at 11 m. The thermocline remained well developed until early October with a maximum change in temperature of -1.1 to -2.4 °C m^{-1}. Samples from z2 were collected above the thermocline (lower epilimnion) during the July to October stratified period and from the hypolimnion at z3. The only exception was on 3-Oct-97 when z3 was located at the thermocline in the metalimnion.

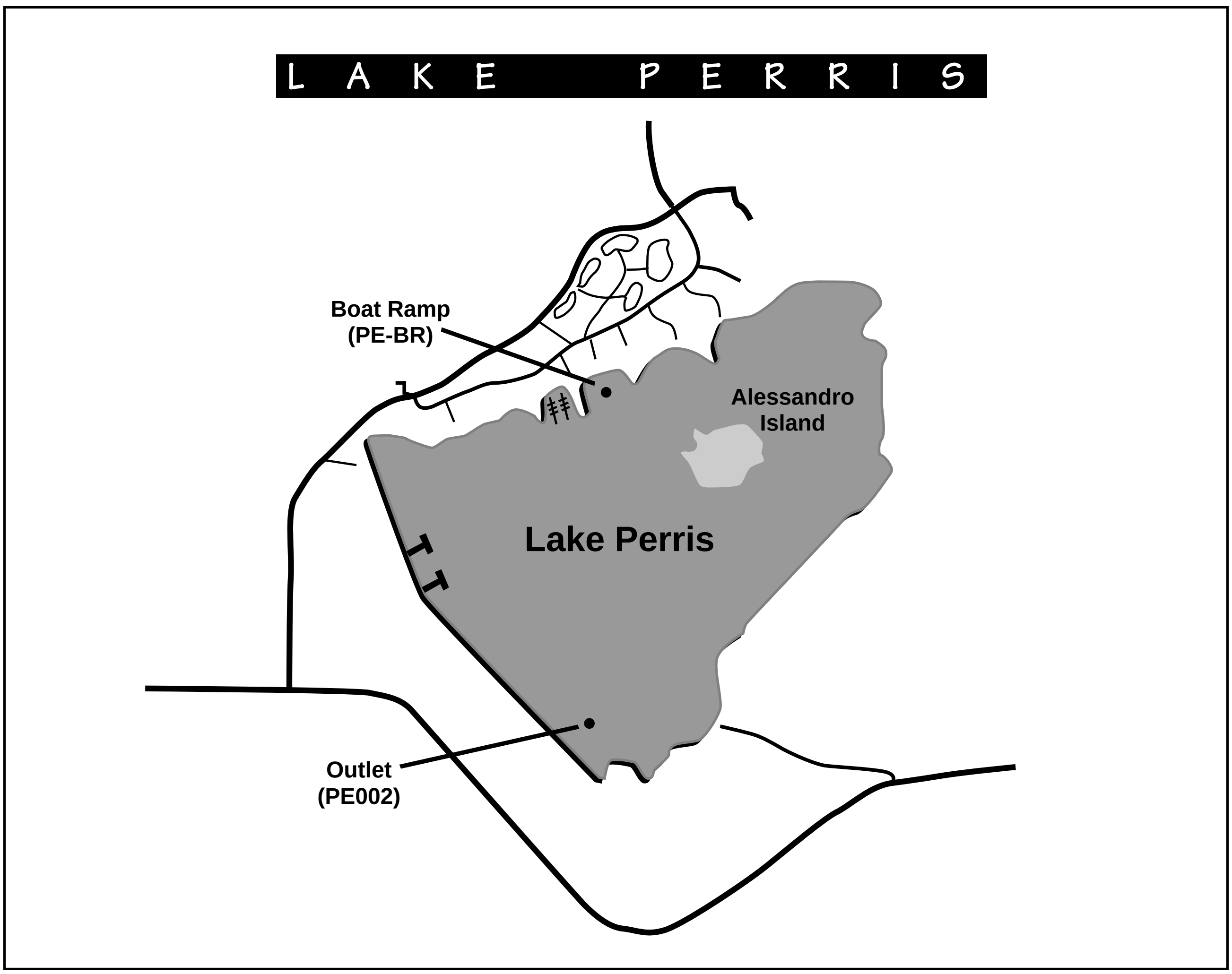


Figure 23. Map of Lake Perris sampling sites, 1997

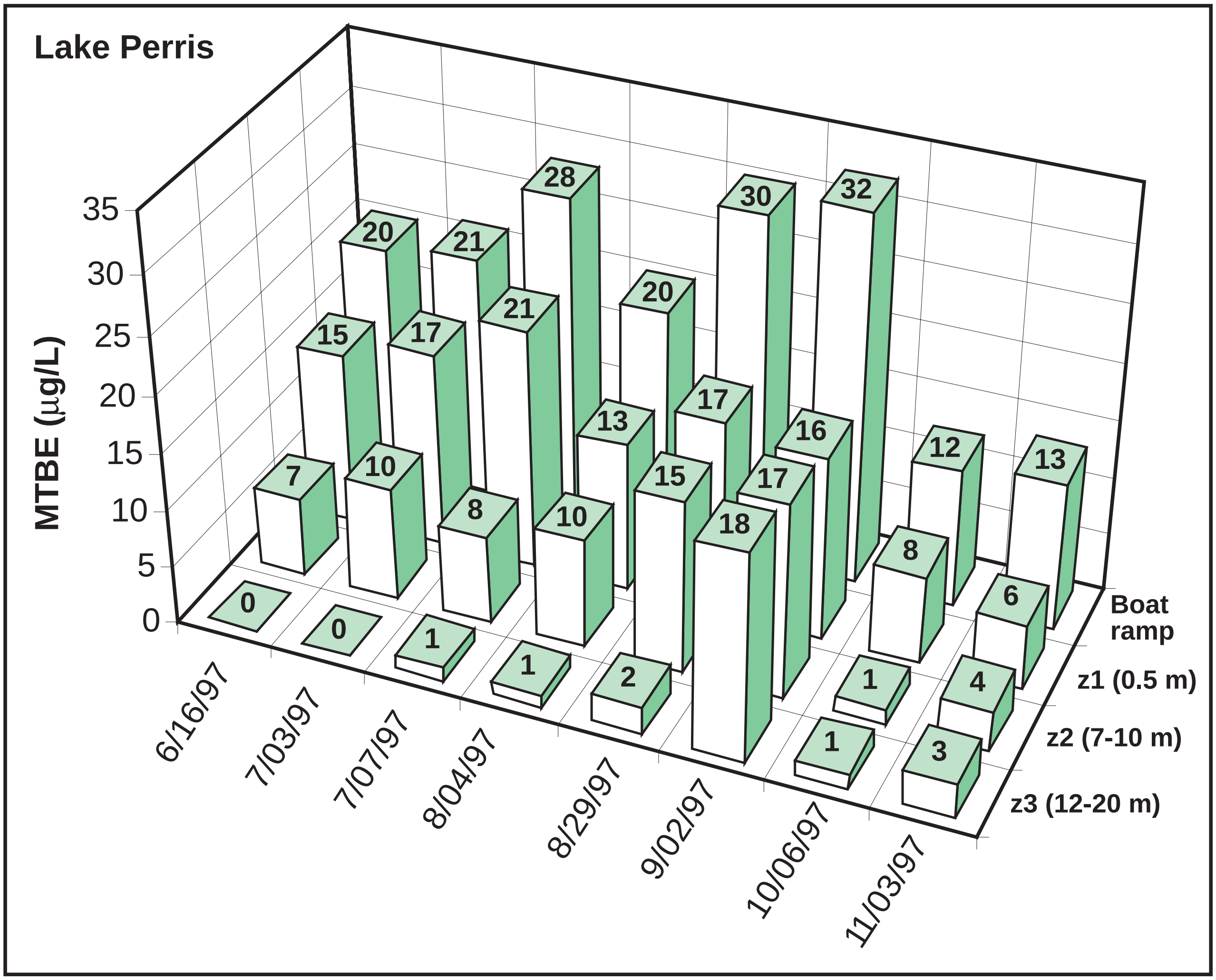


Figure 24. MTBE concentrations at boat ramp (PE-BR) and Lake Perris outlet (PE002), 1997.

Table 29. Sample and thermocline depth (m) at Lake Perris outlet, 1997.

	Sample depth (m)			Thermo-	Max.
Date	**z1**	**z2**	**z3**	**cline**	**Δ °C/m**
6/16/97	0.5	10	16	-	-0.1
7/03/97	0.5	7	15	8	-0.8
7/07/97	0.5	8	15	11	-2.0
8/04/97	0.5	8	14	10	-1.1
8/27/97	0.5	8	12	10	-1.5
9/02/97	0.5	8	12	10	-2.4
10/06/97	0.5	8	16	16	-1.6
11/03/97	0.5	8	20	-	-0.1

MTBE at the boat ramp was high throughout the study and ranged from 12 to 32 µg/L (mean = 22 µg/L, SD = 7.5). The highest concentrations of 30 and 32 µg/L were found on Labor Day weekend (29-Aug and 02-Sept).

MTBE at the outlet was detected in all samples from the surface (z1) and z2. Seventy-five percent (6) of 8 samples from depth z3 had detectable levels of MTBE (**Fig 24**).

At z1, MTBE ranged from 6 µg/L in November to 21 µg/L in July with a mean of 14.1 µg/L **(Table 30)**. MTBE in the lower epilimnion (z2) ranged from 1 µg/L in October to 17 µg/L on 29-Aug-97 (mean = 8.9 µg/L).

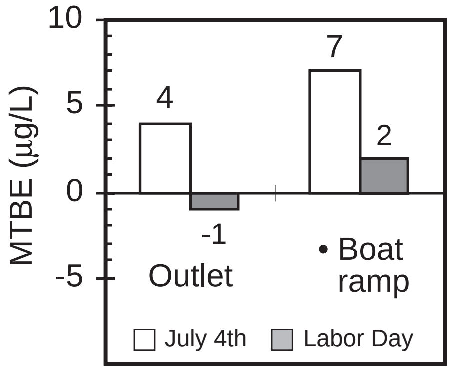


Figure 25. Change over holiday weekends in surface MTBE (µg/L) at Lake Perris;
July 4th = MTBE on 7-Jul-97 — 3-Jul-97;
Labor Day = 2-Sep-97 — 29-Aug-97.
Positive values indicate an increase.

MTBE in the hypolimnion was in the range of 1 to 3 µg/L during most of the season except on 2-Sept-97 when a value of 18 µg/L was detected. The sample was collected 2 m below the well developed thermocline (maximum temperature change of -2.4 °C m^{-1}).

Post July 4th MTBE concentrations were higher than pre-holiday values at the Outlet and boat ramp (**Fig 25).** MTBE on 7-Jul-97 was 4 µg/L and 7 µg/L higher at the Outlet and boat ramp, respectively. MTBE at the Outlet was lower after Labor and increased by 2 µg/L at the boat ramp.

Table 30. Mean MTBE (µg/L) in Lake Perris, 1997.
[S, surface (0.5 m); n, number of samples; S.D., standard deviation; nd, non-detectable]

	Depth	Mean	n	S.D.
Boat ramp				
	S	22.0	8	7.5
Reservoir				
Outlet	z1	14.1	8	5.1
(PE002)	z2	8.9	8	5.3
	z3	3.4	8	6.0

Table 31. MTBE and BTEX compounds detected in Lake Perris, 1997.

Date	Station	Depth (m)	VOC's	µg/L
16-Jun-97	Outlet	0.5	MTBE	15.0
			Total xylene	0.7
			Toluene	1.0
	Boat ramp	0.5	MTBE	20.0
			Total xylene	0.5
			Toluene	0.7
4-Aug-97	Boat ramp	0.5	MTBE	20.0
			Total xylene	2.6
			1,2,4-Trimethylbenzene	0.5
			Toluene	1.7
			Benzene	0.6
29-Aug-97	Boat ramp	0.5	MTBE	30.0
			Total xylene	2.7
			1,2,4-Trimethylbenzene	0.8
			Toluene	2.4
			Benzene	0.6
3-Nov-97	Boat ramp	0.5	MTBE	13.0
			Total xylene	0.9
			1,2,4-Trimethylbenzene	0.7
			Toluene	0.6

MTBE and BTEX compounds were detected in 16 percent (5) of 32 samples from Lake Perris (**Table 31**). Five of 8 boat ramp samples (63 percent) had detectable levels of BTEX compounds. In addition to total xylene, and toluene, 1,2,4-trimethylbenzene and Benzene were each detected in 2 samples. When detected, total xylene and toluene concentrations ranged from 0.5 to 2.7 µg/L and 0.6 to 2.4 µg/L, respectively.

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OEHHA, 1999. Public Health Goal for Methyl Tertiary Butyl Ether (MTBE) in California Drinking Water. Office of Environmental Health and Assessment. (available at http://www.oehha.org/docs/phgs/pdf_zip/mtbe_f.pdf)

Health and Environmental Assessment of MTBE

Report to the Governor and Legislature
of the State of California as Sponsored by SB 521
Delivered to the Governor's office on November 12, 1998

All documents below are in pdf format. If you do not already have a copy of the Adobe Acrobat reader you will need to download and install it in order to read the documents.

Fact Sheet

A three page summary of the report.

Press Advisory

Released 11/12/98.

The RFP and Description of the Grant Recipients.

Also includes several relevant links on MTBE.

Peer Review Comments About This Report

The Cal EPA has posted a summary of the Peer Review Comments to this report. This site also includes transcripts of the public hearings.

Author's Responses to Reviewer's Comments

All the reviewers address critisisms in Volume I, they are listed below by the additional volume they address.

- Volume I & Volume III, Chapter 1 response NEW! (48KB, 13 pgs, requires Acrobat 3.0) Submitted by Catherine Koshland et. al. on 3/17/99.
- Volume I & Volume IV, Chapter 1 response (121KB, 65 pgs, requires Acrobat 3.0). Submitted by Graham Fogg on 2/22/99.
- Volume I & Volume V, Chapter 1 response (65KB, 2 pgs., requires Acrobat 3.0). Submitted by Mike Johnson on 2/22/99.
- Volume I & Volume V, Chapter 7 response (62KB, 3 pgs., requires Acrobat 3.0). Submitted by Arturo Keller on 3/15/99.
- The reviewers comments being addressed here are available on the Cal EPA web site.

Volume I: Summary & Recommendations

1. Executive Summary, Recommendations, Summary (295KB, 61 pgs., complete). You can also download the errata for this volume.
   Arturo Keller, Ph.D., John Froines, Ph.D., Catherine Koshland, Ph.D., John Reuter, Ph.D., Irwin (Mel) Suffet, Ph.D., Jerold Last, Ph.D.

Volume II: Human Health Effects

1. An Evaluation of the Scientific Peer-Reviewed Research and Literature on the Human Health Effects of MTBE, its Metabolites, Combustion Products and Substitute Compounds (1.4MB, 267 pgs., complete)
   John Froines, Ph.D., Michael Collins, Ph.D., Elinor Fanning, Ph.D., Rob McConnell, M.D., Wendie Robbins, Ph.D., Ken Silver, M.S., Heather Kun, Rajan Mutialu, Russell Okoji, MSPH, Robert Taber, M.D., MPH, Naureen Tareen, MPH, Catherine Zandonella

Volume III: Air Quality & Ecological Effects

1. Evaluation of Automotive MTBE Combustion Byproducts (242KB, 53 pgs., Figures 1-18 and Appendix A at end of document omitted)
   Catherine Koshland, Ph.D., Robert Sawyer, Ph.D., Donald Lucas, Ph.D., and Pamela Franklin

2. Effects of Oxygenates on Vehicle System Components (172KB, 27 pgs., complete, but tables at end are "fax" quality)
   Elvin R. Monzon and Ian M. Kennedy, Ph.D.

3. Toxicity of MTBE to Freshwater Organisms (76KB, 19 pgs., complete)
   Inge Werner, Ph.D. and David Hinton, Ph.D.

4. Acute Testicular Toxicity of MTBE and Breakdown Products in Lab Mice (99KB, 23 pgs., complete, but titles in tables at end are damaged)
   Joseph Billitti, Ph.D., Brian Faulkner, and Barry Wilson, Ph.D.

5. Ecological Risks of MTBE in Surface Waters (39KB, 10 pgs., complete)
   Michael L. Johnson, Ph.D.

Volume IV: Ground & Surface Water

1. Impacts of MTBE on California Groundwater with errata inserted in red (640KB, 100 pgs., Figures 4, 9-11 and table G4 omitted, titles for figures in appendix H damaged). You can also download the errata for this volume.
   Graham E. Fogg, Ph.D., Mary E. Meays, James C. Trask, Christopher T. Green, Eric M. LaBolle, Timothy W. Shenk, and Dennis E. Rolston, Ph.D.

2. Leaking Underground Storage Tanks (USTs) as Point Sources of MTBE to Groundwater and Related MTBE-UST Compatibility Issues (151KB, 21 pgs., complete, but titles of most figures are damaged, won't print on most black and white printers (invalid colorspace).)
Kevin Couch, Thomas Young, Ph.D.

3. Methyl tert-Butyl Ether in Surface Drinking Water Supplies (113KB, 45 pgs., All tables and figures omitted)
John E. Reuter, Ph.D., Brant C. Allen, and Charles R. Goldman, Ph.D.

4. Transport and Fate Modeling of MTBE in Lakes and Reservoirs (1.1MB, 41 pgs., not complete)
Stephen A. McCord & S. Geoffrey Schladow, Ph.D.

Volume V: Risk Assessment, Exposure Assessment, Water Treatment & Cost-Benefit Analysis

1. Exposure of Humans to MTBE from Drinking Water (213K, 13 pgs., complete, includes the tables omitted in the paper version)
Michael L. Johnson, Ph.D.

2. MTBE: Evaluation of Management Options for Water Supply and Ecosystem Impacts (259K, 38 pgs., not complete)
Orit Kalman, Jay R. Lund, Ph.D.

3. Cost and Performance Evaluation of Treatment Technologies for MTBE-Contaminated Water (643K, 41 pgs., complete, includes the figures omitted in the paper version)
Arturo A. Keller, Ph.D., Orville C. Sandall, Ph.D, Robert G. Rinker, Ph.D., Marie M. Mitani, Britta Bierwagen, Michael J. Snodgrass, Ph.D.

4. Estimated Cost Associated with Biodegradation of MTBE (30K, 7 pgs., not complete)
Brett M. Converse and Edward D. Schroeder, Ph.D.

5. Reactivity and By-Products of MTBE Resulting from Water Treatment Processes (302K, 25 pgs., not complete)
Paulette Chang and Thomas Young, Ph.D.

6. Sorption for Removing MTBE from Drinking Water (718K, 27 pgs., not complete)
Irwin (Mel) Suffet, Ph.D., Thomas Shih, M.S., Eakalak Khan, Ph.D., Medhi Wangpaichitr,
Wei Rong, M.S., Jenifer Kong

7. An Integral Cost-benefit Analysis of Gasoline Formulations Meeting California Phase II Reformulated Gasoline Requirements (430KB, 56 pgs., complete. Includes table 14 omitted in the paper version.)
   Arturo A. Keller, Ph.D., Linda Fernandez, Ph.D., Samuel Hitz, Heather Kun, Alan Peterson, Britton Smith, Masaru Yoshioka

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Omitted Tables

We inadvertantly omitted tables or figures from three chapters in the original paper documents. You can download the updated documents or just the omitted tables and figures below.

- Table 1 and 2 from the end of volume 5, chapter 1, *Exposure of Humans to MTBE from Drinking Water* by Michael L. Johnson were omitted. You can view the updated chapter or just the omitted tables.
- The figures a the end of volume 5 chapter 3, *Cost and Performance Evaluation of Treatment Technologies for MTBE-Contaminated Water* by Arturo A. Keller, et. al. were omitted. You can view the updated chapter or just the omitted figures.
- Table 14 at the end of volume 5 chapter 7, *An Integral Cost-benefit Analysis of Gasoline Formulations Meeting California Phase II Reformulated Gasoline Requirements* by Arturo A. Keller, et. al. was also omitted. You can view the updated chapter or just the omitted table.

Because we wanted to upload the files in as timely a manner as possible, some figures and tables from the original paper documents have been omitted. The authors can also be contacted directly for copies of the tables.

Errata for Volumes 1 and 4

Minor corrections have been submitted by Graham Fogg to volumes 1 and 4 are available as erratta below.

- Volume I errata. (updated 2/22/99)
- Volume IV errata. (updated 2/22/99)

Please send corrections to the TSR&TP Webmaster